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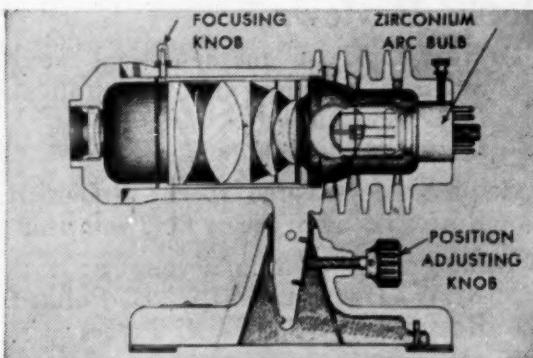
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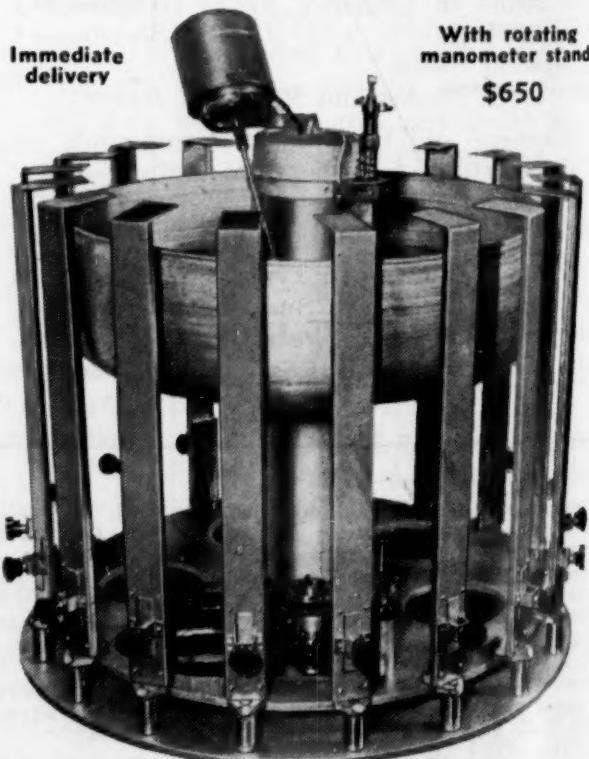
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Luminescent Solids (Phosphors)

H. W. Leverenz

Radio Corporation of America, RCA Laboratories Division, Princeton, New Jersey

IT IS A CURIOUS FACT that man synthesized and used luminescent solids long before detecting luminescence from the natural luminescent solids which have existed on this earth since its genesis. About 350 years ago, the alchemist Casciarolo chanced to heat some native barium sulphate with charcoal and noticed that after exposure to daylight the cooled impure sulphide product glowed feebly in the dark. This mysterious solid, which was called a *phosphor* or phosphorus (Greek, "light bearer"), antedated the discovery of the chemical element phosphorus by about 70 years. Because the similarity of terms has caused some confusion, it should be noted that the luminescence of a phosphor is a solid-phase *physical* (electronic) action which occurs throughout the mass and which may continue indefinitely when the phosphor is in a vacuum; whereas the luminescence of the element misnamed phosphorus results from a gas-phase *chemical* action which occurs only at the surface and which ceases when the phosphorus is consumed or placed in a vacuum.

At the time phosphors were first prepared, daylight was the only known means for their excitation, and so luminescence was observable only when it was excitable by daylight and persisted long enough for the phosphor to be taken into a dark place. With the development of modern electronic and radioactive sources of invisible radiations, phosphors have been used not only for instantaneous detection of ultraviolet, X-rays, cathode-rays, alpha particles, etc., but also as a means of putting these invisible forms of energy to work in television, radar, electron microscopes, "fluorescent" lamps, infrared spiperscopes, X-ray fluoroscopes, and self-luminous dial markings. This article briefly outlines the present status of man-made phosphors, whose variety and capabilities greatly exceed those of the known natural luminescent solids. More detailed information may be obtained from the references at the end of this article.¹

Before proceeding, it is worth emphasizing that the technology of phosphors, like that of other structure- and impurity-sensitive, electronically active solids (*e.g.*, photoconductors, semiconductors, ferroelectric and ferromagnetic materials), is in the process of growing from the status of an art to that of a science.

Our imperfect understanding and control of electronically active solids is caused largely by the practical impossibility of completely segregating (purifying) and rectilinearly arranging (crystallizing) the enormous number of atoms ($10^{23}/\text{cm}^3$) in *real* crystals, so that real crystals are always impure and imperfect to some degree. It is known that the unavoidable imperfections (including impurities) in real crystals sometimes increase and sometimes decrease electronic activities such as excitation, internal ionization, radiative and nonradiative transitions, electron mobility, and trapping. Very often, certain crystal imperfections are incorporated deliberately to promote or suppress a given electronic activity. In the case of phosphors, the highly purified *host crystal* usually has a very small proportion of *activator* impurity which is either added initially or is induced to increase luminescence efficiency. The efficiency increase is generally accomplished by decreasing the proportion of excitation energy dissipated in the crystal as heat.

LUMINESCENCE

There is a maximum characteristic thermal radiation from any solid at a given temperature, T , and *luminescence* may be defined broadly as the production of photon emission in *excess* of this thermal radiation. In contrast with thermal radiation, luminescence emission generally decreases with increasing T and occurs as narrow spectral lines or bands (Fig. 1) whose locations and shapes are relatively insensitive to changes in T . Luminescence is generally a *nonequilibrium* process wherein extraneous photons or charged material particles (electrons, ions, etc.) bombard a material and excite a few of its atoms or groups of atoms (*centers*) to energy levels far higher than those attained by thermal excitation. The excited centers then return to lower energy levels and emit correspondingly high-energy photons.

Distinctive prefixes are used to denote luminescence produced by primary particles which differ in the manner in which they excite phosphors, *e.g.*, visible and near-visible photons excite *photoluminescence*, X-ray and gamma-ray photons excite *roentgenoluminescence*, electrons excite *cathodoluminescence*, and ions, such as alpha particles, excite *ionoluminescence*. The energies of these primary excitant particles generally exceed 2 electron volts (ev), where 1 ev =

¹ Most of the information in this article is abstracted from the author's book, *Introduction to luminescence of solids*, New York: John Wiley, in press.

1.6×10^{-12} erg = 3.8×10^{-20} calorie = 23 kcal mole⁻¹ (when each simple molecule has 1 ev), there being no known upper limit (at least to 10^8 ev) to the energy of a primary particle capable of exciting phosphors.

about 10^{-8} or 10^{-9} second for the nonmetastable excited states of isolated atoms or ions undergoing the optical transitions which occur in conventional luminescence. The natural lifetimes of isolated atoms are

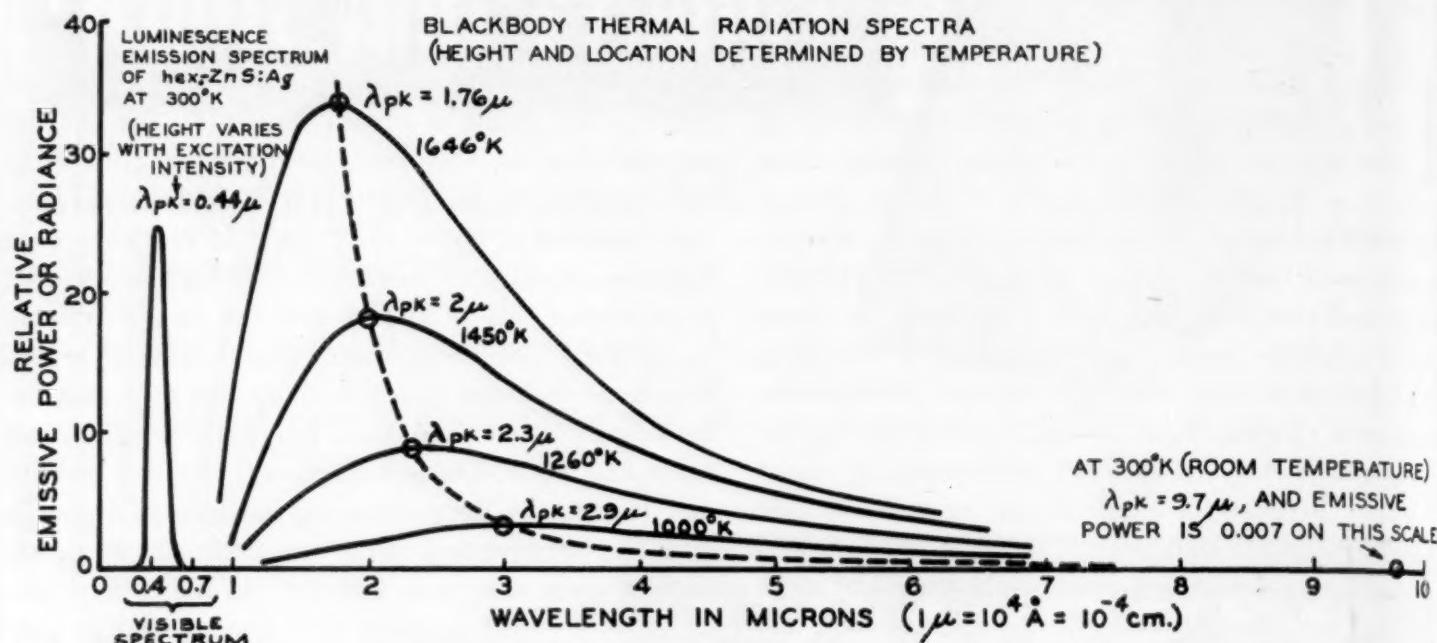


FIG. 1. Comparative spectral distributions of the emissions from a typical phosphor (narrow band at left) and a blackbody thermal emitter (broad bands at right).

The energies of the photons emitted during *conventional luminescence* range from about 1 ev (1.24×10^{-4} cm = $12,400\text{\AA}$) to 10 ev (0.124×10^{-4} cm = $1,240\text{\AA}$), while the energies of emitted X-ray and gamma-ray luminescence photons extend well beyond this range up to about 10^7 ev. This article is concerned chiefly with the conventional visible and near-visible luminescence of solids, which generally involves transitions of the outer or valence electrons comprising the "skins" of atoms. These exposed electrons are sensitive to changes in the kind, number, spacing, and arrangement of neighboring atoms in a solid, and the luminescence of solids is thus a sensitive indicator of changes in composition, impurities or other imperfections, and crystal structure. Also, the valence electrons of an atom in a solid experience most strongly the jostling caused by thermal motion of atoms, so that increasing the temperature of the solid generally perturbs the luminescence process and increases the probability of conversion of high-energy excitation quanta into low-energy thermal quanta (phonons).

With respect to the duration of luminescence, *fluorescence* indicates a normal, unconstrained, spontaneous radiative return from the excited state (as in isolated nonmetastable atoms or ions), whereas *phosphorescence* indicates an abnormally long delay between excitation and emission, using *isolated* atoms or ions as standards of normal behavior. Fluorescence, then, is a limiting case of phosphorescence and corresponds to a natural excited-state lifetime, τ_F , of

determined chiefly by oscillator damping (classically, $\tau_F \propto \nu^{-3} \rho_d^{-2}$ for radiation of photons of frequency ν from a dipole with moment ρ_d), and the width of a fluorescence emission line is determined by the indeterminacy of the excited-state energy level, ΔE^* , such that $\Delta E^* \geq h/\pi\tau_F$, where $h = 6.62 \times 10^{-27}$ erg sec. This line width is only about 10^{-7} ev for conventional fluorescence with $\tau_F \approx 10^{-8}$ second, whereas many phosphors have emission bands nearly 1-ev wide and their emissions persist for seconds or days (i.e., the band widths and persistences of phosphors are often unrelated). Most phosphors exhibit predominantly an abnormally delayed emission, which is called phosphorescence. Here, the abnormal delay may be caused by (1) the strong perturbing (constraining) influence of neighboring atoms on excited centers in solids, and/or (2) internal ionization and trapping. *Internal ionization* is the ejection of an electron from an excited atom or center, without the electron's leaving the solid. The vagrant excited electron may become trapped, particularly near imperfections in the crystal, and remain trapped for an indefinite time before being released by heat or other energy so that it can again wander to make a radiative recombination with an ionized center.

In general, phosphors begin to emit luminescence photons within 10^{-8} second after onset of excitation, but very often much of the excitation energy is stored in the form of prolonged (constrained) excited states or trapped excited electrons so that photon emission

is extended for intervals ranging from a few seconds to a few years after cessation of excitation, the duration of phosphorescence depending on the nature of the phosphor and its conditions of excitation and operation. When a large proportion of the excitation energy is stored, the curve of luminescence output *vs.* time exhibits a detectable *growth* (Fig. 2) until equilibrium is established, *i.e.*, until the rate of filling and emptying of excited states and traps has stabilized in the excited volume of the solid. After cessation of excitation, there is a *decay* of luminescence output *vs.* time as the stored excitation energy is released. When there is simple excitation, without internal ion-

primary factor in determining τ . In this case, the spontaneous *exponential decay* is little affected by changes in the temperature of the phosphor or the conditions of excitation.

The emitting center loses control over τ when the energy storage in phosphors consists of trapped excited electrons or metastable states, for then additional *activation energy* must be supplied to release the trapped electrons. This activation energy may be supplied by heat, especially when the trap depth is equal to or less than about $30 kT$ (where $k = 1.38 \times 10^{-16}$ erg deg $^{-1}$ = 8.7×10^{-5} ev deg $^{-1}$), or it may be supplied by additional photons or charged material

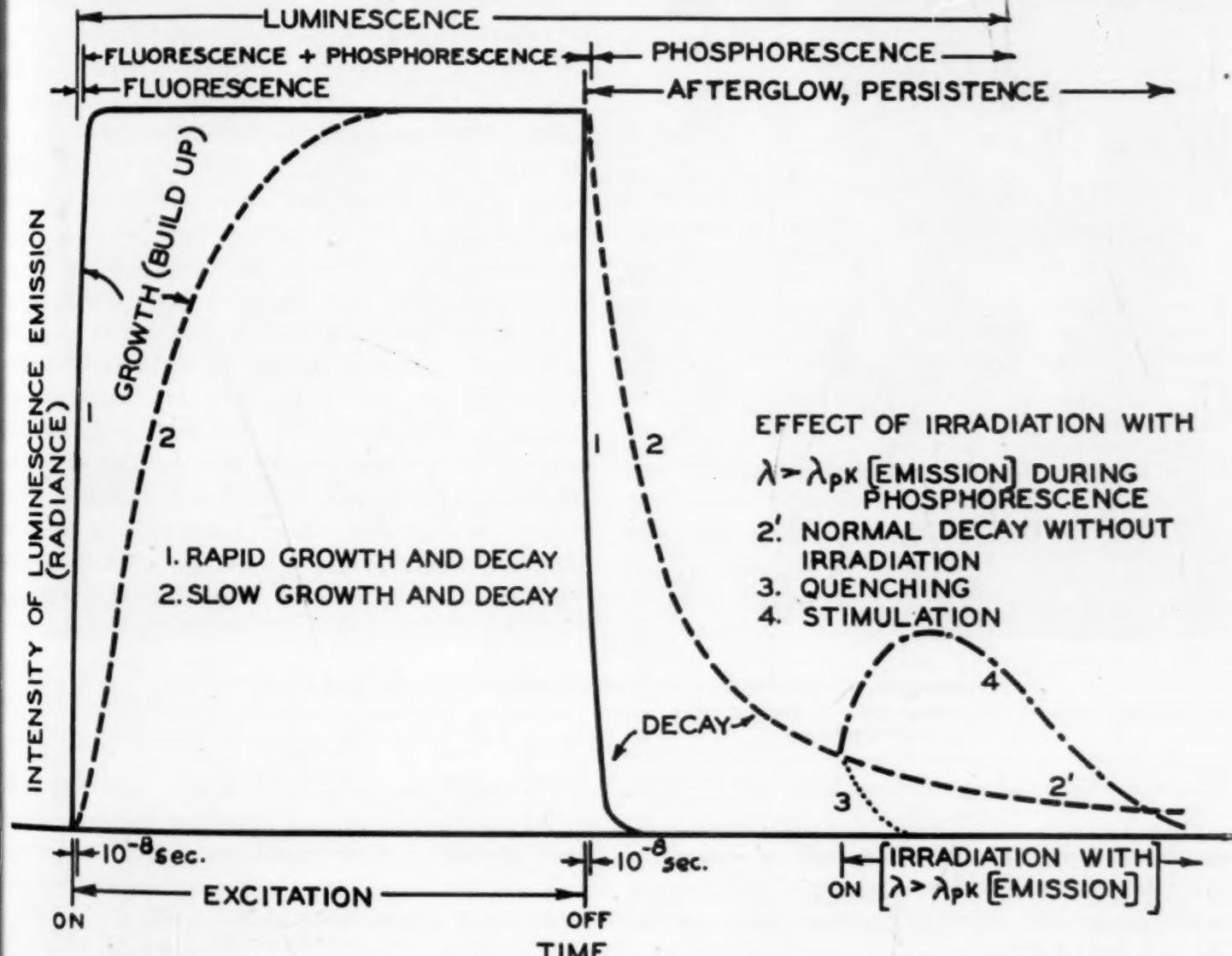


FIG. 2. Diagrammatic representation of the dynamics (growth and decay) and terminology of luminescence emission.

zation and trapping, the rate of emission of luminescence photons, L , decreases exponentially with time, t , according to $L = L_0 e^{-at}$, where L_0 is the luminescence output at cessation of excitation and the decay constant a ($= \tau^{-1}$) ranges from about 10^7 to 1 sec $^{-1}$, depending on the composition and structure of the phosphor. It is to be expected that τ will be larger and, hence, a will be smaller the more constraint an excited emitting atom or center experiences from its neighbors in the crystal, but the emitter itself is a

particles. During ordinary phosphorescence at room temperature the activation energy is supplied by heat, so this process is thermostimulated phosphorescence. Under these conditions, so-called *power-law decays* are observed such that $L \propto L_0 t^{-n}$, where the exponent n is strongly dependent on the phosphor temperature and on the kind, intensity, and duration of excitation; also, n varies during the decay interval. In general, n has values lying between about 0.1 and 2, being near unity for most of the useful phosphorescence times

of efficient long-persistent phosphors. The variability of n bespeaks the variable degree of filling and

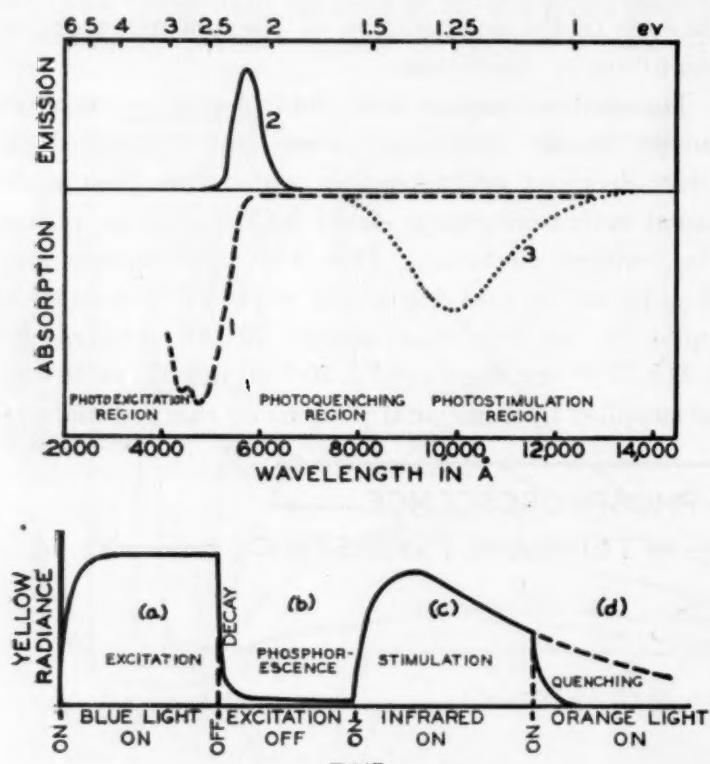


FIG. 3. *Above*: Spectral distributions of excitation, quenching, and stimulation for a cub-Sr(S:Se) : SrSO₄ : CaF₂ : Sm : Eu phosphor. *Below*: Dynamics of growth and decay of the above phosphor during and after (a) excitation, (b) decay, (c) stimulation, and (d) quenching.

rate of emptying of traps of different densities and depths, and the variable occurrence of retrapping, since the density of excitation decreases in a roughly exponential manner as the beam of primary excitant particles penetrates into a phosphor crystal.

in curve 4 of Fig. 2. Because the quenching and stimulating effects for a given phosphor vary with wavelength, a broad-band source of red and infrared may act as both a quenching and stimulating agent simultaneously. The top portion of Fig. 3 shows the spectral relationships of excitation, emission, quenching, and stimulation for a complex infrared-stimulable phosphor of the type used in metascopes for infrared detection and signalling. The bottom portion of Fig. 3 shows how the yellow emission band may be produced by excitation with blue light ($\approx 4,500 \text{ \AA}$), allowed to decay, stimulated by infrared ($\approx 10,000 \text{ \AA}$), and quenched by orange light ($\approx 6,000 \text{ \AA}$).

The complex chemical formula (which is really an oversimplification!) for the infrared-stimulable phosphor of Fig. 3 serves as an extreme example of the system of notation used in symbolizing luminescent solids. The chief ingredients of a good phosphor are the host crystal, one or more fluxes (fusible salts which are not always used), and one or more activators (promoters of luminescence) which may be added deliberately or be induced by decomposition during crystallization at high temperatures. Examples of other useful phosphors and their notations are given in Table 1. According to the indicated simplified notation, a phosphor is symbolized by (1) the crystal system of the host crystal, followed by (2) the chemical formula of the host crystal, then by (3) any fluxes which are incorporated in the host crystal (this is not the case in examples 1-3 of Table 1), and finally by (4) the chemical identity of the activator cation [placed in square brackets when there is uncertainty

TABLE 1
COMPOSITIONS, PREPARATIONS, AND DESIGNATIONS OF SOME TYPICAL PHOSPHORS

No.	Ingredients			Cryst. temp.	Post- cryst. treat- ment	Phosphor notation	Decay type
	Host crystal	Flux	Added activator				
1.	1 ZnS (i.e., 97.44 g ZnS)	2 g NaCl	.....	1250° C	wash	hex.-ZnS : [Zn]	t^{-n}
2.	1 ZnS	2 g NaCl	0.017 g AgNO ₃	"	"	hex.-ZnS : Ag(0.01)	"
3.	1 ZnS	2 g NaCl	0.013 g CuCl ₂	"	"	hex.-ZnS : Cu(0.01)	"
4.	2 ZnO + 1 SiO ₂ (162.76 g + 60.06 g)	....	.....	"	...	rbhdl.-Zn ₂ SiO ₄ : [Si]	$t^{-n} \rightarrow t^n$
5.	2 ZnO + 1.02 SiO ₂ (162.76 g + 61.26 g)	....	0.02 TiO ₂ (1.6 g)	"	...	rbhdl.-Zn ₂ SiO ₄ : Ti(0.4)	"
6.	2 ZnO + 1.012 SiO ₂ (162.76 g + 60.78 g)	....	0.012 MnO (1.1 g)	"	...	rbhdl.-Zn ₂ SiO ₄ : Mn(0.3)	"

Infrared is another useful source of activation energy which may (1) be unabsorbed (i.e., be entirely reflected or transmitted) and hence cause no change in the normal decay curve shown as 2' in Fig. 2, or (2) be absorbed and *quench* the phosphorescence emission, as shown in curve 3 of Fig. 2, or (3) be absorbed and *stimulate* the phosphorescence emission, as shown

as to its identity or presence] with the weight percent of activator cation relative to the weight of the host crystal given in parentheses.

EXEMPLARY SYNTHESSES OF PHOSPHORS

The phosphor compositions given in Table 1 are sufficient to prepare efficient phosphors if except

tionally pure ingredients are used (especially when the optimum activator proportion is low), the ingredients are *thoroughly mixed*, and the mixtures, in acid-cleaned, covered, fused-silica crucibles, are heated in air to the indicated temperatures for ten to a hundred minutes. These examples are typical of the formation of most phosphors by reactions in the solid state, *i.e.*, reactions between solids at temperatures below their melting points and the melting points of

of the zinc-silicate phosphors, no flux is used, and the average particle size of the resultant phosphor is determined largely by the particle size of the initial silica, because the reaction proceeds by diffusion of the zinc and manganese oxides into the silica particles. This is illustrated in Fig. 5, which shows electron micrographs of two different lots of rbhdL-Zn₂SiO₄: Mn(0.3) prepared from (a) exceptionally fine colloidal silica, and (b) an ordinary e.p.

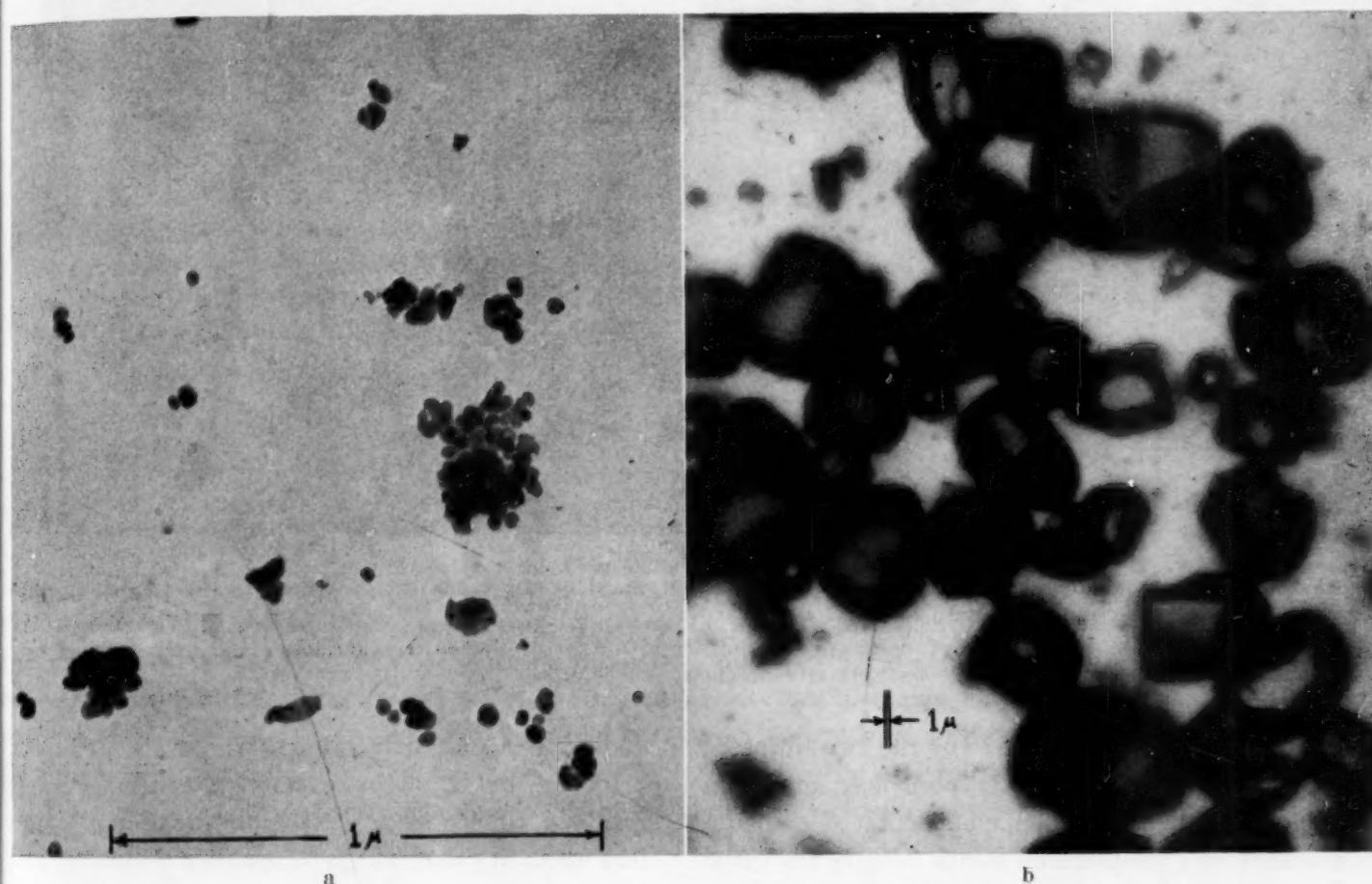


FIG. 4a. Electron micrograph of precipitated-and-dried luminescence-pure zinc sulphide.

FIG. 4b. Photomicrograph of hex.-ZnS: Ag(0.015), prepared by heating the fine-particle ZnS shown in Fig. 4a (with activator and about 6-percent halide flux) at 1,250° C.

their products. (Growth of phosphor crystals from melts is seldom successful because the melting points of the host crystals are usually so high that the melts react vigorously with their containers and the mixtures tend to decompose and volatilize selectively.) Under these conditions of solid-state reaction, the presence of a flux, such as sodium chloride, sometimes promotes crystallization by providing a fluid phase to facilitate material transport. Fig. 4a shows an electron micrograph of a pure, practically nonluminescent, precipitated-and-dried zinc sulphide, which was used as the initial ingredient in preparing phosphors 1-3 of Table 1. Fig. 4b shows a photomicrograph of the much larger phosphor crystals produced by heating this fine zinc sulphide (with flux) to 1,250° C. These hex.-ZnS: Ag(0.015) phosphor crystals are about 10⁸ times larger (in volume and weight) than the initial 250-Å ingredient particles. In the case

silica. (The electron micrographs in Figs. 4 and 5 were made by Dr. J. Hillier.)

As may be seen from Figs. 4 and 5, the average particle sizes of useful phosphors are generally a few microns or less, because finely divided ingredients must be used to obtain complete solid-state reaction in a reasonably short time. The small particle size of phosphors is desirable to increase the absorption of primary ultraviolet in "fluorescent" lamps, and to improve the image definition and optical efficiency of television cathode-ray-tube screens, but it makes difficult the determination of certain fundamental physical characteristics such as absorption spectra, absorption coefficients, and conductivities. It is in only a few cases, such as cub.-KCl: Tl, rbhdL-Al₂O₃: Cr (artificial ruby), and tetr.-CaWO₄: [W] (artificial scheelite), that efficient luminescent crystals of centimeter size have been prepared from their melts. Insofar

as the effect of crystal size on luminescence is concerned, the luminescence of phosphors is a *volume* effect, as evidenced by the fact that (1) cathodoluminescence efficiency increases as the penetration of the

(1) When very pure zinc silicate is crystallized at 1,250° C, the product is found to have an inefficient cathodoluminescence emission shown as curve 4 in Fig. 7. This emission comes from some of the ex-

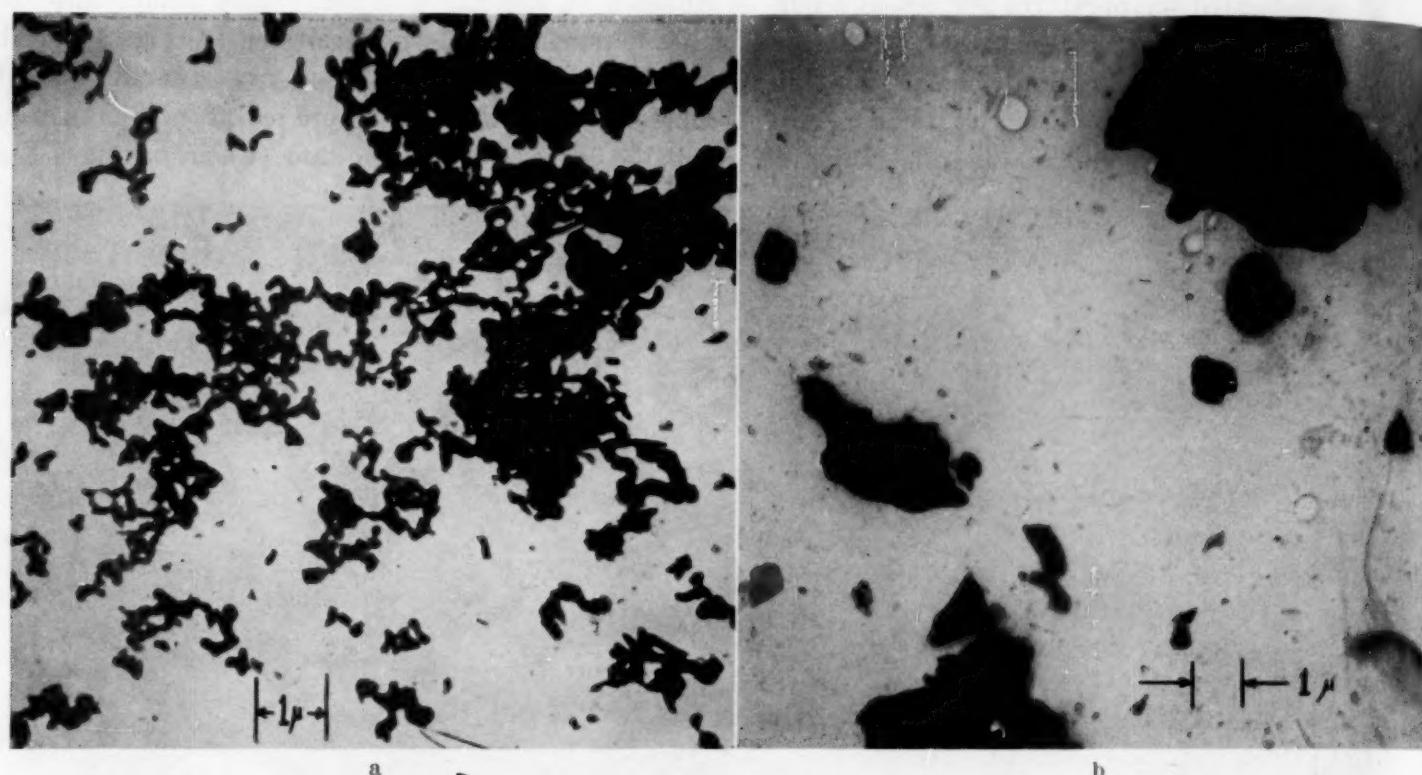


FIG. 5a. Electron micrograph of very-fine-particle rbndl.- Zn_2SiO_4 : Mn which was prepared by reaction of zinc hydroxide and manganese hydroxide with colloidal silica.

FIG. 5b. Electron micrograph of commercial rbndl.- Zn_2SiO_4 : Mn prepared by reaction of the oxides, using conventional pure silica with an average particle size of about one micron.

primary electrons increases, and (2) the two different lots of rbndl.- Zn_2SiO_4 : Mn(0.3) phosphor shown in Fig. 5 have practically the same efficiency of cathodoluminescence and photoluminescence despite the great difference in their particle sizes.

EFFECTS PRODUCED BY IMPURITIES

In general, phosphors consist of relatively nonluminescent host crystals containing a small proportion of added or induced impurities. Impurities can form many different local distorted regions (*e.g.*, centers), as depicted in Fig. 6, and a given impurity may: (1) act as an *intensifier activator* by intensifying a weak or latent host-crystal emission spectrum, (2) act as an *originative activator* by producing a new emission spectrum, (3) act as a *sensitizer* by producing a new excitation spectrum without altering the emission spectrum, (4) act as a *trap* by altering the duration and intensity of power-law-type phosphorescence, and (5) act as a "poison" (or "killer") by decreasing luminescence efficiency.

These examples illustrate these effects and show how a given impurity may function in several of the following roles.

cited tetrahedral SiO_4 groups which are presumably perturbed by a slight excess of silicon [Si] (or [Zn]?) produced by selective volatilization of oxygen. Here the [Si] acts as an *intensifier activator*, probably by upsetting the selection rules which govern electronic transitions in ideal crystals. When about a percent of titania is incorporated in this phosphor, the same emission band is obtained with about a ten-fold increase in efficiency (cf. curve 5, Fig. 7). Here, the titanium (in the combined form!) is an additional intensifier activator. In the same way, silver appears to act as an intensifier activator for zinc-sulphide phosphors, operating to increase the efficiency with only a slight shift and narrowing of the emission band (curves 1 and 2, Fig. 7).

(2) When rbndl.- Zn_2SiO_4 : [Si] is reheated at 1,250° C with increasing proportions of manganese oxide, the [Si] emission band decreases and a new emission band rises in the green until, at about one percent Mn, only the strong green emission is evident (curve 6, Fig. 7). Here, the Mn (which substitutes for Zn) acts as a *poison* in preventing the [Si] emission, and simultaneously acts as an *originative activator* in producing the new centers which emit luminescence photons with high efficiency. Similarly,

copper activator poisons the blue [Zn] emission band of hex.-ZnS: [Zn] while producing a new green emission band (curve 3, Fig. 7). Present evidence indicates that the best originative activators are added

tained as before and the phosphors are now readily excited by 2,537- \AA ultraviolet. Here the (combined) lead acts as a *sensitizer* which introduces a new absorption band in the spectral region around 2,537 \AA .

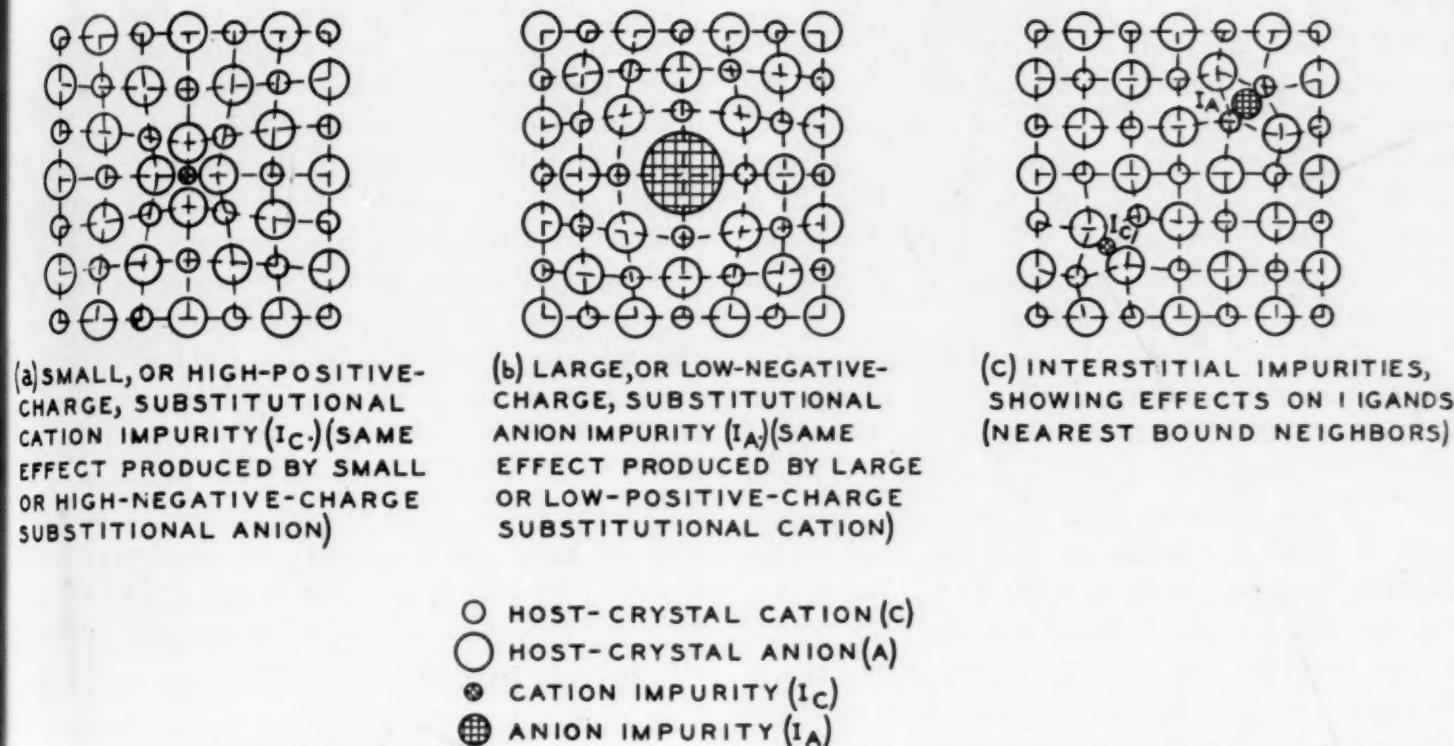


FIG. 6. Examples of typical distortions produced by impurities in host crystals.

ions, which exhibit more than one formal valence (e.g., Mn^{++} , Mn^{++++} and Cu^+ , Cu^{++}), whereas intensifier activators may be either added or induced, and need not be multivalent (e.g., $[Zn^{++}]$, $[Si^{++++}]$; Ti^{+++} , Ti^{++++} ; and Ag^+ , Ag^{++}).

(3) When calcium carbonate or calcium silicate is crystallized with about one percent of manganese ac-

(4) In the previous example of hex.-ZnS: Cu, the multivalent Cu acts not only as a poison and an activator but also as a *trapping agent*. This is evidenced by intense and prolonged phosphorescence at room temperature and by pronounced glow curves (curves of light output vs. temperature and time as a phosphor previously excited at very low temperatures is warmed). By incorporating a lead compound in this phosphor, it is found that the lead provides very deep traps, such that the phosphor performs in the same manner as the infrared-stimulable material in Fig. 3. In the case of rbhdl.-Zn₂SiO₄: Mn, it has been found that tin and arsenic compounds are effective in providing traps without altering the emission spectrum of the phosphor.

(5) In addition to the previous examples of poisons, it may be mentioned that manganese in trace amounts is a strong *poison* to the emission of calcium-tungstate phosphors. Also, certain other transition elements, particularly iron and cobalt, are strong poisons in almost all phosphors.

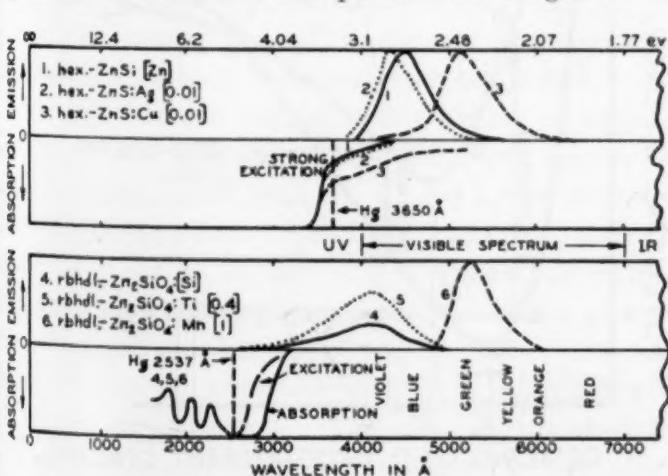


FIG. 7. Spectral distribution of absorption, excitation, and luminescence emission of some typical zinc-sulphide-type and zinc-silicate-type phosphors.

tivator, the phosphors are found to have efficient red-orange cathodoluminescence, but no appreciable photoluminescence under 2,537- \AA ultraviolet. If, however, these phosphors are reerystallized with a small proportion of lead oxide in addition to the added manganese oxide, then the same red-orange emission is ob-

EFFECTS PRODUCED BY CHANGES IN STRUCTURE

The pronounced influence of structural changes on the luminescence of solids is shown in the following examples:

(1) When rbhdl.-Zn₂SiO₄: Mn (denoted as the *a*-form) is melted at 1,600° C and then quenched, it

crystallizes in a new (β -form; undetermined) structure having a different diffraction pattern. On comparing the α and β products, it is found that: (1) the emission band of the α -form peaks at 5,250 Å, whereas the emission band of the β -form peaks at 5,630 Å; (2) the β -form has about 75 percent of the cathodoluminescence and photoluminescence efficiency of the α -form; and (3) the α - and β -forms have practically identical exponential decay characteristics. On heating the yellow-emitting β -form to about 950° C, it reverts to the green-emitting α -form, demonstrating that the observed effects are caused by changes in structure rather than composition.

(2) When ZnS : [NaCl(2)] : Ag(0.01) is heated at 780° C it crystallizes in the cubic system, whereas on heating at 1,200° C it crystallizes in the hexagonal system. On comparing these two products, it is found that: (1) the emission band of the cubic material peaks at 4,480 Å, whereas the emission band of the hexagonal material peaks at 4,330 Å; (2) the hexagonal material has about four times the peak output of both cathodo- and photoluminescence relative to the cubic material; and (3) although both materials have power-law decays, the intensity and duration of phosphorescence emission of the hexagonal material is much greater than that of the cubic material at room temperature. On grinding, the hexagonal crystals are transformed into the cubic structure.

LUMINESCENCE EXCITATION

When a beam of primary excitant particles impinges upon a phosphor crystal, some particles are reflected, whereas others are transmitted into the interior of the crystal. The energy of a transmitted primary photon is absorbed all at once or not at all (neglecting Compton scattering) in one absorption act wherein the photon is annihilated. The energy of a fast primary electron or ion, on the other hand, is usually absorbed bit-wise, where the average energy bit is about 25 ev. Differences in excitation processes are evident, also, with respect to where the energy is absorbed in a phosphor crystal. Low-energy primary ultraviolet photons often excite phosphor centers directly, because the centers generally have lower characteristic frequencies than the atoms of the host crystal. High-energy primary particles (e.g., X-ray and gamma-ray photons, and fast electrons and ions), however, give up their energies indiscriminately, so that most of their energy is absorbed by the preponderant host-crystal atoms. In this case, the absorbed energy must be transported to the centers and the efficiency of such energy transport depends strongly on the degree of perfection of the crystal. Hence, there are many photoluminescent glasses and crystals with

high efficiency, but only highly crystalline phosphors give high efficiency of roentgenoluminescence, cathodoluminescence, and ionoluminescence. The high rate of degradation (into heat) of energy transported in vitreous matter accounts, also, for the fact that only crystalline phosphors give efficient, long-persistent, power-law-decay phosphorescence involving wandering and remote trapping of excited electrons.

It is probable that most of the energy transport in phosphors is by excited "free" electrons, although other means are: positive holes, excitons, photons, and exchange-type energy transfers which occur when the wave functions of atoms and centers overlaps in a suitable manner. Positive holes are residual regions of excess positive charge produced by internal ionization, and excitons are mobile pairs of positive holes and nearly-free excited electrons. The problems of energy transport in solids are complicated by the interplay of ionic (electrostatic) and covalent (shared-electron) bonding between the atoms, and by the pronounced influences of imperfections and different structural arrangements in crystals.

LUMINESCENCE MECHANISM

For lack of specific information about the energy levels in phosphors, two complementary types of simplified energy-level diagrams have been devised to give

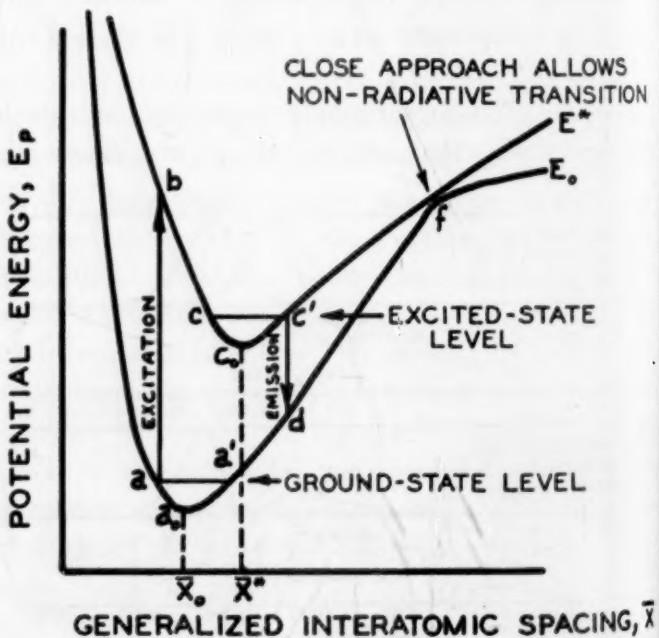


FIG. 8. Configuration-coordinate energy-level diagram of a phosphor impurity center, where the potential energy of the center is plotted as a function of the average distance between the atoms in the center.

a generalized picture of the mechanism of luminescence. One such diagram, shown in Fig. 8, depicts the allowed potential energies of a *luminescence center* as a function of averaged interatomic spacing, \bar{x} , where \bar{x}_0 is the averaged spacing between the atoms

of the unexcited center at equilibrium. At 0°K, the ground-state energy level would be very near a_0 , corresponding to minimum potential energy and minimum atomic vibration. At room temperature, however, the system (center) has considerable vibrational energy, so the ground-state level lies higher, such as at a , where the amplitude of atomic vibration is proportional to $a'-a$ (imagine the system passing through a_0 as it rolls from a to a' and back, in the potential well). When a bit of excitation energy of adequate magnitude, usually greater than 2 ev, is transmitted to the center, the energy of the center may be raised from a on the ground-state curve, E_0 , to b on the excited-state curve, E^* . Within about 10^{-12} second after excitation, the atoms of the excited center readjust to a new equilibrium spacing, \bar{x}^* , and the energy difference $b-c$ is given up as heat to the surrounding host crystal. With the center in the excited-state level c , the probability of a radiative transition from c' to d is determined by the natures of the impurity and host crystal, being practically independent of temperature, but the probability of a nonradiative transition to the ground state via $c' \rightarrow f \rightarrow a$ increases exponentially with temperature. Here, then, the observed phosphorescence for this luminescence without internal ionization is practically independent of the temperature when $kT \ll \Delta E$, or of the kind, duration, and intensity of excitation; and the decay proceeds according to

$$L = L_0 e^{-(a + \nu_a e^{-\Delta E/kT})t}$$

where the atomic vibration frequency, ν_a , is about 10^{12} sec⁻¹, and the thermal activation energy, ΔE , is the energy difference $f - c_0$. The observed decrease of luminescence efficiency with increasing temperature may be visualized as a raising of level c so that an increasing proportion of excited states "spill over" via f without producing radiation. If, at any given temperature, the levels c and f practically coincide, then the center is a *poison* in that it is a means for rapidly degrading excitation energy into heat. This picture, then, illustrates how a center which produces luminescence at low temperatures may be a poison center at higher temperatures. The number of available efficient phosphors decreases rapidly with increasing operating temperature, with hardly any phosphors having useful efficiencies above 400° C. In general, phosphors should be operated at as low temperatures as possible, although some power-law-decay phosphors exhibit an intermediate optimum operating temperature where traps are efficiently emptied by thermal energy.

Another type of energy-level diagram, shown in Fig. 9, depicts the energy levels of a luminescence center as a function of distance along a row of atoms

in the crystal. This type of diagram emphasizes the fact that the discrete energy levels of isolated atoms are spread out into bands in solids, the broadening being caused by interaction of the electrons of all the atoms in the crystal, because the Pauli exclusion principle allows only two electrons (of opposite spin) to occupy the same energy level in a given system. The diagram is drawn for a specific \bar{x} , so one must imagine that the spacings and potential barriers between the atoms change with every energy change of the center. According to the diagram, the impurity atom, I_C : (1) lowers the normal potential barriers between the host-crystal atoms in its vicinity, (2) introduces an additional occupied level, E_I , into the forbidden zone of host-crystal energies, and (3) introduces additional discrete unoccupied excited-state levels, $E_{I_n}^*$, whose extensions into the surrounding crystal increase as $E_{I_n}^*$ increases until, in the conduction band, E_C^* , an excited electron is free to move through the host crystal. The excitation transition $E_I \rightarrow E_{I_1}^*$ in Fig. 9 corresponds to $a \rightarrow b$ in Fig. 8, and the radiative return $E_{I_1}^* \rightarrow E_I$ corresponds to $c' \rightarrow d$. As drawn, this process is highly localized, and the spontaneous decay is exponential. When the low-lying, highly localized excited state, $E_{I_1}^*$, is absent, and the center is excited to higher levels wherein the excited electron may wander some distance away from its parent atom, then the electron may become trapped at a distant point, where it must be released by an additional activation energy before it can return to make a radiative transition from a low-lying $E_{I_n}^*$ level. When the excited electron travels through the conduction band, E_C , it may be trapped by a remote unexcited center, forming a new filled level (e.g., E_{I^-}). This type of trapping is most probable when the impurity is a multivalent ion; for example, a Sm⁺⁺⁺ impurity can trap an extra electron to become Sm⁺⁺. Regardless of whether the excited electron is trapped in a metastable state in its center of origin or in a remote center, the phosphorescence is strongly dependent on temperature and on the kind, duration, and intensity of excitation. The complex decay then proceeds by thermally activated release of trapped electrons according to

$$L = L_0 e^{-\nu_{a_1} t e^{-\Delta E_1/kT}} + L_0 e^{-\nu_{a_2} t e^{-\Delta E_2/kT}} + \dots + L_0 e^{-\nu_{a_N} t e^{-\Delta E_N/kT}}$$

where the subscripts 1, 2, 3 ··· N denote traps of different densities and depths ΔE_1 , ΔE_2 , ΔE_3 , ..., ΔE_N which make different contributions L_{0_1} , L_{0_2} , L_{0_3} , ..., L_{0_N} to the luminescence output at time $t=0$. This lengthy expression is usually shorthanded by the power-law-decay approximation $L = L_0 t^{-n}$, since, as

previously noted, n varies not only with the type of phosphor, but with the temperature, decay time, and conditions of operation. Both exponential and power-

transition as do the highly localized untrapped excited electrons responsible for the predominant exponential decay. As is to be expected from Fig. 9, electronic

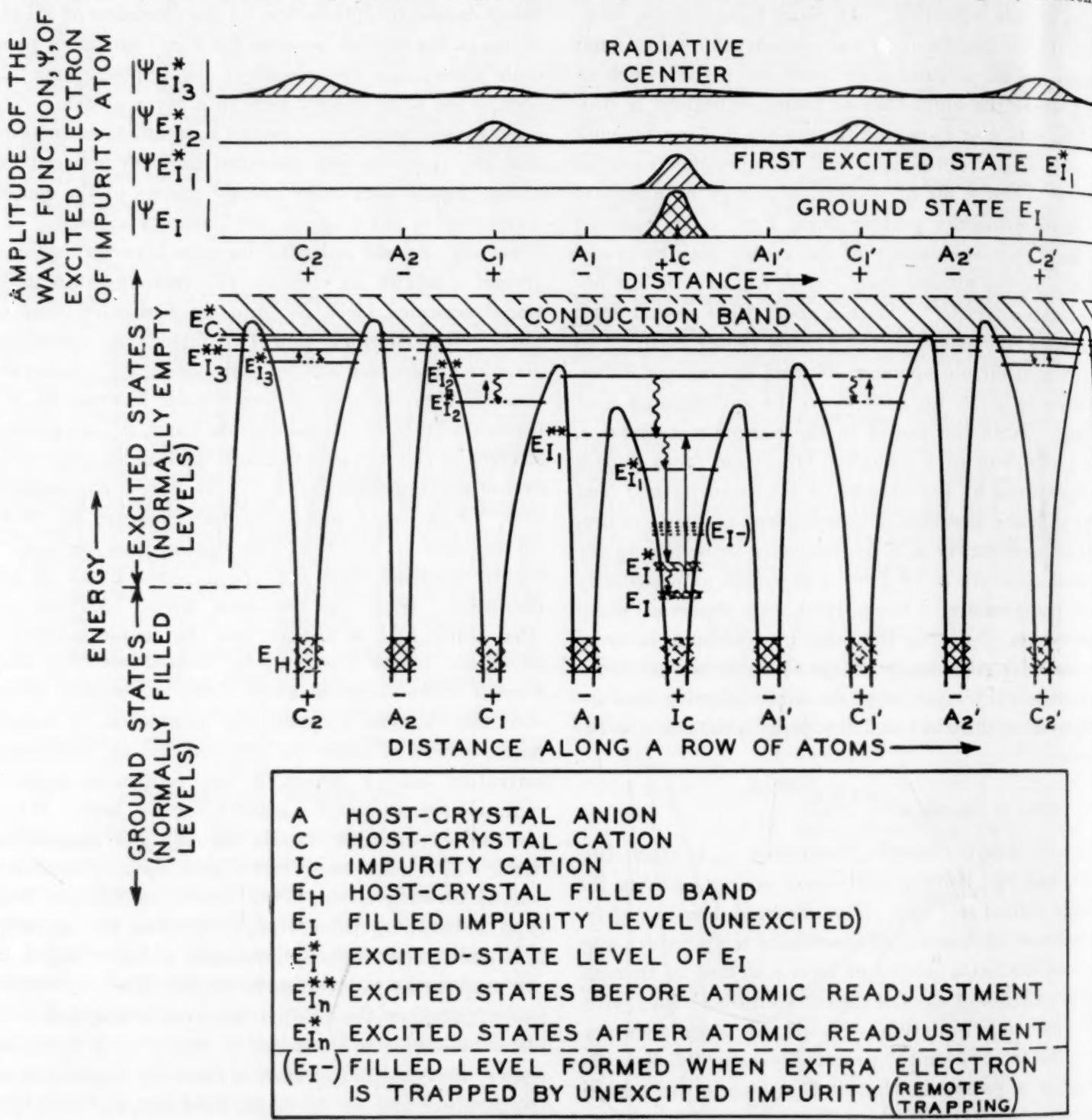


FIG. 9. Energy-level diagram of a row of atoms in a phosphor impurity center. The lower part of the figure shows the lowering of the potential barriers in the neighborhood of the impurity, and the relatively discrete occupied and excited-state energy levels introduced by the impurity. The upper part of the figure shows a plot of the absolute value of the wave function, ψ , of the optical electron responsible for luminescence (ψ^2 is a measure of the probability of finding the electron in a given location). The breadths of the excited-state levels increase with height and so the upper levels may overlap each other and the conduction band.

law decays can occur, without change in spectral distribution, by exciting a center such as the one generalized in Fig. 9 to $E_{I_1}^{**}$ and higher levels, as long as the final radiative transitions take place from $E_{I_1}^*$ to E_I^* . Almost all phosphors which exhibit initial exponential decays eventually trail off into power-law "tails" which bespeak the delayed returns of distant trapped electrons that make the same final radiative

conduction parallels the growth and decay of many power-law-decay phosphors, whereas little or no conduction is observed when the decay is predominantly exponential.

Stimulation of phosphorescence by low-energy (long-wavelength) photons, as in Fig. 3, is readily understood by picturing the weak photons as having just enough energy to raise trapped electrons out of

their traps so they can make radiative recombinations with the parent ionized centers. Quenching of phosphorescence by higher-energy photons, however, apparently involves exciting the system to a high-energy level near or above f in Fig. 8, i.e., the trapped excited electron is raised so high in energy that the surrounding atoms are set in violent agitation and the excitation energy is dissipated as heat.

LUMINESCENCE EMISSION SPECTRA

Both line and band emission spectra may be produced separately or simultaneously by phosphors. Line spectra are obtained when radiative transitions take place between discrete highly localized energy levels. Such discrete levels often occur when well-oxidized impurity ions with incomplete inner shells (e.g., Eu⁺⁺⁺ and Cr⁺⁺⁺) form luminescence centers. For example, ThSiO₄: Eu(1), crystallized at 1,250° C in oxygen, gives a line emission spectrum attributable to electrons with unpaired spins in the *inner*, well-shielded, incomplete 4f shell of Eu⁺⁺⁺ making transitions between discrete subatomic levels having different resultant spin quantum numbers. When this phosphor is heated in a reducing atmosphere, however, the unpaired 4f-shell spins are apparently paired and a band emission is obtained in place of the previous line emission. The band emission is attributed to the *outer* valence electrons of Eu⁺⁺ making transitions between levels having different principal and angular-momentum quantum numbers (where at least one of the levels is a band).

The chemical and structural constitutions of phosphors determine, of course, the locations and breadths of their emission lines and bands. Of about 10⁵ different samples of artificial inorganic phosphors that have been synthesized here and abroad, the most useful phosphors have band widths of the order of 0.7 ev, although lines narrower than 10⁻³ ev and bands broader than 2ev have been obtained in some cases. Empirical methods for controlling the locations of emission bands in almost any part of the visible and near-visible spectrum have been developed for several efficient phosphor families where variations in host-crystal composition, in particular, afford excellent control over the properties of the resultant phosphors. For example, increasing partial substitution of cadmium for zinc (or selenium for sulphur) in any of the three zinc-sulphide phosphors shown in Fig. 7 gradually shifts the emission spectrum toward the infrared. At present, the white-emitting luminescent screens of direct-viewing television cathode-ray tubes are made of a mixture of blue-emitting hex.-ZnS: Ag(0.01) and complementary yellow-emitting hex.- $\frac{1}{2}$ ZnS · CdS: Ag(0.01). (The latter phosphor is also

useful for X-ray fluoroscope screens.) Similarly, luminescent screens for direct-viewing color television may be obtained by selecting appropriate blue-, green-, and red-emitting members of this phosphor family. In the case of the outstandingly useful phosphor family based on rbhdl.-Zn₂SiO₄: Mn(1), increasing substitution of germanium for silicon produces a gradual shift of the emission band toward the red, but when beryllium is substituted in increasing proportions for the zinc, the original green emission band peaked at 5,250 Å decreases and a new orange-red emission band rises at 6,300 Å. The high activator proportions of silicate phosphors make them particularly useful for operation under conditions of intense excitation. For example, the three different luminescent screens for the three (trinoscope) cathode-ray tubes used in laboratory demonstrations of color television on a theatre scale may be made of blue-emitting rbhdl.-Zn₂SiO₄: Ti(1), green-emitting rbhdl.-Zn₂SiO₄: Mn(1), and red-emitting rbhdl.-Zn₈BeSi₅O₁₉: Mn(2). White-emitting luminescent screens for "fluorescent" lamps are made either by mixing blue-emitting monocl.-Mg₂WO₅:[W] with yellow-emitting rbhdl.-Zn:Be₂SiO₄: Mn, or by using a cadmium(or calcium)-fluoro(chloro)-phosphate: Mn: Sb phosphor whose two different activators produce two complementary emission bands. It may be noted that the influence of new host-crystal atoms should depend not only on the nature of the new atom, but also on whether the new atom becomes an immediate neighbor or just a near neighbor of the emitting atom or center, and whether the luminescent center is founded on a substitutional or interstitial impurity.

LUMINESCENCE EFFICIENCY

When phosphors are excited by low-energy photons (*photoluminescence*), quantum efficiencies exceeding 90 percent have sometimes been obtained. For example, the phosphor coating of a green-emitting "fluorescent" lamp converts over 90 percent of the input 2,537-Å (4.9-ev) primary photons into emitted luminescence photons having an average energy of about 2.4 ev (5,250 Å). On an energy basis, this luminescence process is $(2.4/4.9)90 \approx 45$ percent efficient. In some cases, the energies of the primary and emitted photons lie even closer together, so that the energy efficiency may be higher. It is rare, however, that the energy efficiency of photoluminescence of phosphors exceeds about 80 percent, because there is always some gap between the peaks of their excitation and emission bands (*cf.* Fig. 7). For a given average energy of the emitted photons $\bar{h\nu}_{em}$, the energy efficiency, \mathcal{E} , decreases with increasing energy of the excitant photons, $\bar{h\nu}_{ex}$; i.e., $\mathcal{E} \propto \bar{v}_{em}/\bar{v}_{ex}$. This is true

until \bar{v}_{ex} becomes large enough to produce internal photoelectrons with sufficient energy to produce in turn more than one luminescence photon. When this happens, as it does for excitation by X-rays and gamma-rays (*roentgenoluminescence*), the luminescence process is essentially cathodoluminescence.

When phosphors are excited by fast charged material particles (*cathodoluminescence* and *ionoluminescence*), the energy efficiency is vanishingly small for low primary-particle energies because slow particles dissipate their energies in the inefficient (distorted and chemically different) surface layers of the phosphor crystals. It is only in rare cases that detectable luminescence output can be obtained from phosphors excited by 5-ev primary electrons, and even at primary energies of thousands of volts the energy efficiency does not exceed about 10 percent. The low efficiency which obtains even when the primary particles penetrate well into the efficient volumes of phosphor crystals is attributed to the large difference between the absorbed energy bits (approximately 25-ev average) and the emitted photons (approximately 2.5-ev) and to the difficulties of energy transfer from the predominant host-crystal absorber atoms to the fewer activator centers.

LUMINESCENCE OUTPUT

The radiances of phosphors *during* excitation by photons are limited mostly by the low intensities of available photon sources. With available sources of ultraviolet, for example, the maximum luminances of visible-light-emitting phosphor screens are of the order of 5,000 millilamberts (mL), or about 2×10^{16} photons emitted per square centimeter per second. On the other hand, brief instantaneous luminances exceeding 10^7 mL (over 10^{20} photons $\text{cm}^{-2} \text{ sec}^{-1}$) can be obtained from phosphor screens struck by a well-focused, high-voltage, scanning cathode-ray beam, although the sustained averaged luminance of such a scanned screen generally may not exceed about 10^5 mL (4×10^{17} photons $\text{cm}^{-2} \text{ sec}^{-1}$) without heating the screen above the temperature range in which appreciable luminescence efficiency is obtained. (It may be recalled that fresh snow in full sunlight has a painful luminance of about 10^4 mL.) In a conventional direct-viewing television cathode-ray tube, producing 50 to 100 mL in the image highlights, a given screen element the size of the cathode-ray-beam area is excited for about 1.5×10^{-7} second, 30 times a second, for a summed duration of only 16 seconds of actual operation time per 1,000 hours of total operation time. On this basis alone, it seems odd that the efficiency of the screen should change somewhat during 1,000 hours elapsed (16 seconds actual) time of operation. During the actual operation time, however, the instantan-

eous power input into a screen element is about $10,000 \text{ volts} \times 2 \times 10^{-4} \text{ ampere}/0.001 \text{ cm}^2 = 2000 \text{ watts/cm}^2$. This power loading is almost ten times as high as the 250 watts/ cm^2 absorbed power input (and radiated power output) of a tungsten filament in an ordinary incandescent lamp. In projection cathode-ray tubes, the power loadings may be several orders of magnitude higher than in direct-viewing cathode-ray tubes.

The radiances of phosphors *after* excitation are determined by their decay characteristics and light sums under the operating conditions. The *light sum* is the total radiance per unit area integrated over the entire afterglow interval. Integration of the decay curves of trap-type phosphors such as hex.-ZnS : Cu and cub.-Sr(S : Se) : SrSO₄ : CaF₂ : Sm : Eu (taking into account the penetration of the primary particles) has shown that about 10^{18} potential photons/ cm^3 may be stored in the excited volumes of some phosphor crystals under favorable conditions. This number is of the same order of magnitude as the number of Cu or Sm impurity centers in the cited phosphors, thus lending additional support to the idea that these impurities are the trapping agents. To a first approximation, the light sum is proportional to (1) the number of excitable centers and traps per unit volume, (2) the depth of penetration of the primary particles, and (3) the intensity and duration of the excitation (up to saturation).

The time interval in which the light sum is practically all released may be varied enormously by careful choice of phosphors and operating conditions. For example, (1) screens of hex.-ZnO : [Zn], cub.-MgS : Sb, and rhomb.-BaSO₄ : Pb give up most of their stored luminescence energy in about 10^{-6} second in cathode-ray tubes used for flying-spot image pickup in television, (2) a cascade screen, wherein a cathodoluminescent blue-emitting hex.-ZnS : Ag phosphor excites a photoluminescent yellow-emitting hex.-9ZnS · CdS : Cu phosphor, emits about 0.03 mL 3 seconds after excitation in radar cathode-ray tubes, and has luminances which are detectable by the well-dark-adapted eye for many hours, and (3) screens of photoluminescent cub.-Sr(S : Se) : SrSO₄ : CaF₂ : Sm : Eu retain most of their light sums for about six months at room temperature, thereby providing useful long-duration retentivity of information and infrared stimulability.

CONCLUDING REMARKS

Man-made phosphors, which were unimportant alchemical novelties during the 17th and 18th centuries, found their first important uses in the 19th century as visible indicators of certain invisible energetic particles, such as ultraviolet and x-ray photons, cathode

rays, and alpha particles. In recent years of the 20th century, the direct conversion of the energies of these invisible particles into light, at operating temperatures near room temperature, has become a major commercial function of phosphors which are now produced at the rate of over 200,000 kilograms a year. Meanwhile, phosphors are finding increasing scientific use in detecting these invisible particles and others, including infrared and gamma-ray photons, fast-moving ions, and even neutrons, by converting their energies into radiations which the human eye may detect directly, or indirectly through other photosensitive devices, such as multiplier phototubes (usually coupled with oscilloscopes or meters), photographic films, or other phosphors used in cascade.

In addition to the practical progress already made by empirical phosphor research, some progress has been made toward developing a qualitative theory of

luminescence of solids, although a useful quantitative theory is not yet available. Luminescence is such a convenient and sensitive indicator of changes of composition, structure, and atomic interactions in solids that it has contributed much to our improved understanding of the solid state of matter. In the future, the practical consequences of this broad aspect of luminescence research may well overshadow the tangible results already obtained.

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The Nature of the Organizer

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APPROXIMATELY TWENTY-FIVE YEARS AGO, Spemann and Hilde Mangold demonstrated that the dorsal lip of the blastopore acts as the primary organizer of the amphibian embryo after it is carried inside the gastrula to form a layer of chordamesoderm beneath the ectoderm. The contact thus established between these two layers results in an induction by the chordamesoderm (organizer) of nervous tissue in the overlying ectoderm. Since this discovery was made, an intensive search has been conducted for an explanation of both the stimulus and the response in this reaction. In terms of biochemistry and cellular physiology, however, the precise nature of embryonic induction still eludes us. It may be useful, nevertheless, to summarize the current ideas on the nature of the organizer.

First, let us consider the question of specificity of organizer action. Many studies have suggested that the inducing stimulus is nonspecific. It has been shown that amphibian ectoderm capable of response (competent) can be induced to form neural tissue by an array of inducers, some of which are: 1) living organizers from other vertebrate embryos; 2) extracts from whole embryos or parts of embryos; 3) tissues from the embryonic or adult bodies of many kinds of animals, providing the tissues are first killed by heat, drying, freezing, or treatment with organic

solvents; 4) certain chemical compounds, such as cephalin, digitonin, and various polycyclic hydrocarbons; and 5) chemical or physical conditions that cytolyze some of the ectodermal cells with the release of toxic products evoking a neuralizing response in the surviving cells. Actually there may be no distinction between the last two categories.

Spemann (11) himself was finally inclined to the conclusion that the inducing stimulus is nonspecific and Holtfreter (8, p. 34) has recently taken this position, pointing out that neuralization of competent ectoderm "can be achieved by the application of various agents which have not more in common than the faculty of increasing the permeability of the cell membrane, and of causing cytolysis if applied in excess." If this interpretation is correct it follows that the factors for specificity of the reaction lie within the ectoderm.

On the other hand, there are studies which suggest that inducers are not qualitatively alike and that the specificity of induction does not reside entirely within the reacting system. Evidence supporting this interpretation includes the following points. 1) The results of experiments on regional determination indicate differences in the action of the organizer along the primary axis of the embryo. Thus, anteriormost mesoderm induces brain and sense organs, whereas more posterior levels induce spinal cord. 2) Dead

inductors differ from living organizers in that the response to the former lacks the organization and completeness of anatomical pattern (individuation) which characterize the secondary embryo developing in response to a living organizer. Holtfreter (8, p. 33) refutes this point, however, as follows: explants of competent ectoderm stimulated by cytolyzing agents "differentiate not merely into a heap of neural cells, but the previously nonorganized cells become integrated into anatomical patterns which can be identified as brain diverticula. If these formations are covered by a mantle of epidermis the latter frequently forms nasal pits and frontal glands . . . the original concept of the organizer as an all-powerful individuating agent should be revised. Furthermore, the data available leave little doubt that it is futile to make a distinction between living inductors and artificial 'evocators.'" Holtfreter admits, however, that "posterocephalic" inductions were not obtained by the action of cytolyzing agents and that, furthermore, mesodermal structures have never been observed in the explants. 3) Living inductors can evoke mesodermal structures; dead ones usually do not. Chuang (5), for example, observed the induction of muscle, notochord, pronephros, and other mesodermal structures by fresh mouse kidney. Induction of notochord and pronephros failed if the kidney had been boiled for five minutes and no mesodermal structures were obtained if it had been boiled for fifteen minutes. Moreover, boiling for varying periods changed the relative frequency with which the several ectodermal organs were formed. Holtfreter (7) had observed earlier that prolonged boiling of a tissue or heating to 135° C reduced the activity of the inductor, and a temperature of 172° completely abolished it. 4) It was observed by Waddington (12) that boiled nuclei were better inductors than boiled cytoplasm with respect to percentage of inductions obtained and volume of induced structures. Chuang found also that newt liver and mouse kidney were unlike in their inductive actions.

These examples are sufficient, I think, to indicate the type of evidence supporting the contention, on the one hand, that inductors are nonspecific and, on the other hand, that they are different in their action and that some measure of the specificity in response is a function of the stimulus. Unfortunately, as Needham (9) has so clearly stated, we have no adequate test for induction. A response by competent ectoderm is unsatisfactory because ectoderm itself may possess the inducing agent in a bound or masked form. Ventral ectoderm which cannot induce when living will stimulate neuralization if killed. We lack a reacting system which will respond to a neuralizing stimulus but which is incapable of acting as an inductor alive or dead.

We may proceed further in our analysis, however, if we assume that the critical agent in induction is the same irrespective of whether the stimulus comes from *without* the ectoderm or whether it is released *within* the ectoderm. According to the first concept (lefthand side of Fig. 1) a nonspecific stimulus produces a change in permeability of the inner membranes of the ectodermal cells which somehow sets off

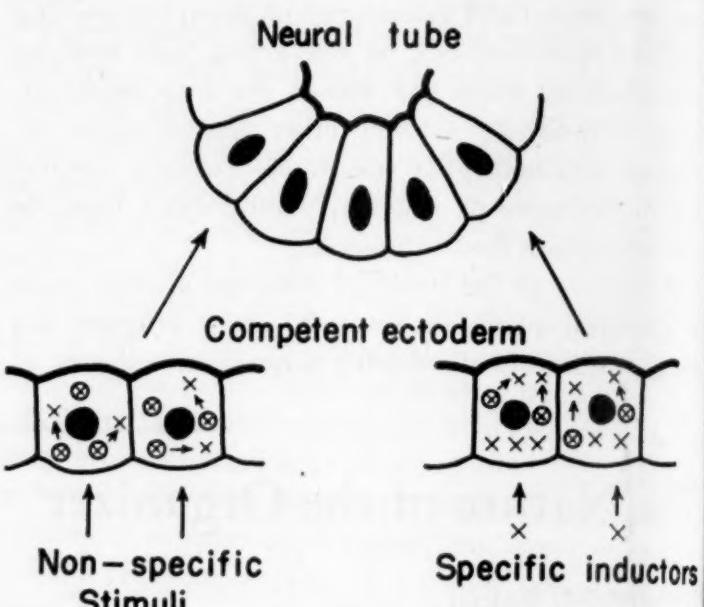


FIG. 1.

the chain of reactions leading to the formation of a neural tube. Maybe a bound substance (encircled x) is released, or perhaps it is synthesized and then, like a virus, is self-duplicated within the cells. In any event, free x is the critical inducing agent. According to the second concept (righthand side of Fig. 1), free x of specific qualities is provided by an inductor—in the living embryo by the mesoderm—which diffuses into the ectoderm and initiates neuralization. Release of bound x or its synthesis and self-duplication might follow secondarily. In both schemes x is the same. What is x?

Two principal suggestions as to the chemical nature of the inducing agent have been proposed: Needham's sterol theory and Brachet's nucleoprotein theory. Needham (9) postulated that the cells of the dorsal lip possess the inducing steroid substance in a bound form—perhaps in a polysaccharide-protein-sterol complex. In the course of gastrulation the characteristic metabolism of the organizer breaks down the complex, releasing the sterol which induces the overlying ectoderm to form a neural tube. Evidence presented by Needham, Waddington, and their collaborators includes the following points. 1) The inducing activity of ethereal extracts of embryonic and adult tissues was traced to the digitonin precipitate of the unsaponifiable fraction. Later Barth (2) showed that the protein fraction exhibited a greater inducing power. 2) Pure sterols or sterol-like compounds

1. ABB
2. BAR
3. BOE
4. BRA
5. CHU
6. FRI

acted as evocators of a neural response in competent ectoderm. 3) Lastly, the dosage of an active steroid required for induction was very low. In connection with the last point, the work of Shen is cited by Needham as being a strategic piece of evidence. Shen (10) recorded induction with a water-soluble carcinogenic hydrocarbon, dibenzanthracene, in very small concentrations. A maximal response of 41 percent induction of neural tube was obtained with a dose of .0125 γ per embryo. This dosage was much smaller than those of nonsteroid substances required to evoke a neural response and was in the same general range of concentration as that shown by other biologically active substances, such as hormones and vitamins.

Brachet, on the other hand, has extended the earlier suggestion of Barth that the organizer may be a protein, by his studies on the relation of ribonucleic acids to induction. According to Brachet (4) the inducing substance may be a nucleoprotein released from the mesoderm in the form of granules which probably include other substances, possibly enzymes. These granules are then engulfed by the ectoderm within which neuralization is initiated. Another possibility is that the metabolism of the mesoderm splits the nucleoprotein into mononucleotides, which become the activating agents when transferred to the ectoderm. Very briefly, some of the evidence presented by Brachet for a relationship between induction and ribonucleic acid is as follows. 1) Grafts show a decrease in cytoplasmic basophilia in those instances in which they act as an inducer but not in the absence of a response by the ectoderm overlying the graft. Cytoplasmic basophilia is indicative of the presence of ribonucleic acid. 2) Ectoderm which becomes induced to form a neural tube exhibits increased cytoplasmic basophilia, but not if neuralization fails. 3) The inducing power of a variety of nucleoproteins, including plant and virus nucleoproteins, is proportional to their ribonucleic acid content. 4) Crushed eggs or tissues from the early embryo exhibit basophilic granules which after cen-

trifugation are accumulated in the clear layer. This layer, when grafted in a coagulated state, is the only one which exhibits considerable inducing power. 5) Breakdown of the nucleoprotein by thermal or enzymatic methods abolishes its inducing power.

Brachet's suggestion thus far described is in terms of a specific inductor from outside the ectoderm. He points out, however, that ribonucleic acids may be involved in substance x, which is released within the ectodermal cell in response to some nonspecific cytolyzing agent. He has observed that in cytolysis there are changes in cytoplasmic basophilia, namely, a rise at first, followed by a decline—changes suggestive of synthesis and then release or breakdown of ribonucleic acids.

For further analysis of the problem of induction, certain lines of research on the metabolism of the embryo may be rewarding. The researches of Needham, Boell, Barth, Brachet and others (see Boell, 3) are providing data on respiration, enzymatic activities, et cetera. One line of investigation may be especially useful, namely, a study of protein synthesis in the amphibian gastrula and neurula. Using radioactive tracers, Abrams, et al. (1) have shown recently that the amino acid glycine is a probable precursor of the purines adenine and guanine, the purines in nucleic acids. Friedberg and Eakin (6) have studied the uptake of radioactive glycine by the amphibian gastrula and neurula and have obtained evidence of a greater incorporation by the dorsal half of the embryo and probably by the dorsal lip than by ventral regions. Brachet had shown earlier that dorsal halves of gastrulae and neurulae contained more ribonucleic acid than the ventral halves. Such physiological investigations may eventually prove to be decisive in elucidating the chemical nature of the organizer.

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TECHNICAL PAPERS

Thermal Separation of Radiomercury From Radiosodium¹

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A number of physiologic phenomena can be studied best by the simultaneous administration of two or more radioactive isotopes. If their half-lives differ sufficiently, no problems arise. In some instances it is feasible for the separation to be effected chemically, but such a procedure is beyond the realm of most clinical investigations. Physical methods employing counters capable of distinguishing beta from gamma radiation and high from low energy particles are often successful. A mass spectrometer may be used. This report is concerned with the description of a method which is practical for separating

or more of the Hg from a given compound under conditions which are quantitative and simple.

In the present studies the biologic relationship between a mercurial diuretic (Mercuhydrin⁴) and sodium chloride is under investigation. To study the pharmacodynamics of diuresis produced by a mercurial diuretic, it is desirable to use such a compound synthesized with radiomercury ($Hg^{203-205}$). Such a procedure is expensive and time-consuming. This isotope of mercury has a physical half-life of 51.5 days. Its "practical" half-life was found to vary considerably, depending on environmental and chemical conditions, making quantitative, separatory studies of isotope activity extremely difficult. The present experiment was prompted by this discovery.

Thirty samples of an aqueous radioactive Mercuhydrin preparation were accurately measured onto filter paper discs and allowed to dry at room temperature. Similarly, 30 such samples of a solution of radioactive sodium (Na^{22}) chloride were prepared, to which, after drying, was added a known amount of radioactive Mercuhydrin solution. The papers were fixed to tinned discs with rubber paper cement. The three series of preparations

TABLE I
VOLATILIZATION VALUES

Specimen	Tube	Mean \pm S.D. (%) Before heat (cpm)	Mean \pm S.D. (%) After heat (cpm)	Amount remaining (%)	Na^{22} $Na^{22} + Hg^{203-205}$ $\times 100$
$Hg^{203-205}$	A	$3,918 \pm 4.95$	41.3 ± 35	1.05	
Na^{22}	A	$2,193 \pm 4.73$	$2,242 \pm 3.79$	102	
$Na^{22} + Hg^{203-205}$	A	$5,620 \pm 4.93$	$1,995 \pm 6.43$	35.4	35.8
$Hg^{203-205}$	B	$7,881 \pm 6.81$	60 ± 36	0.77	
Na^{22}	B	$3,788 \pm 3.75$	$3,864 \pm 3.95$	102	
$Na^{22} Hg^{203-205}$	B	$10,462 \pm 5.63$	$3,400 \pm 5.91$	32.4	32.4

radioactive mercury² from radioactive sodium³ (Na^{22}) and presumably from other elements with similar thermodynamic constants. The method utilizes the well-known intrinsic property of mercury—its volatility under conditions available in ordinary laboratories.

Mercury, one of the oldest of therapeutic agents, combines with other elements to form many compounds, usually organic, of definite biologic interest. Its organic combinations are characterized by instability. If they are decomposed and the consequent behavior of the Hg is used to advantage, it is possible to remove 99 percent

¹ Aided by a grant from the Life Insurance Medical Research Fund, the War Contract No. W-49-007-Md-389, the Helis Institute for Medical Research, and the Mrs. E. J. Caire Fund for Research in Heart Disease.

² Preparation item No. 47B, $Hg^{203-205}$, U. S. Atomic Energy Commission, Oak Ridge Laboratories.

³ Secured through the courtesy of M. A. Tuve and Dean Cowie, Carnegie Institution of Washington, Department of Terrestrial Magnetism.

were counted by separate, thin mica window Geiger-Müller counters with different sensitivities (Table 1).

After being counted, all preparations were placed alternately in position on a sheet of aluminum measuring $18'' \times 12'' \times \frac{1}{16}''$ and heated in an oven to $250^\circ C$ for one hour and twenty minutes. Upon removal and cooling they were again counted (Table 1). Interference by the rubber cement was shown to be nonexistent.

A mean of more than 99 percent of the mercury of a Mercuhydrin preparation was driven off by heat, whereas under identical conditions a sodium preparation did not change significantly. Naturally, stable mercurial salts or compounds would have to be rendered labile to heat to take advantage of vapor tension and boiling point differences. Further studies of a chemicophysical nature are in progress.

⁴ Produced by Harold Krahne, Edwin Sprengeler, and Darwin Kaestner, through the cooperation of Dr. H. L. Dallell of the Lakeside Laboratories, Milwaukee.

Apricots and Plums as Hosts of Western X-Disease¹

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Stoddard (3) reported that peach, *Prunus persica* Batch., nectarine, *P. persica* var. *nucipersica* Schneid., and chokecherry, *P. virginiana* L., are natural carriers of the X-disease in eastern United States. He was able to transmit the disease by budding to the sand cherry, *P. besseyi* Bailey, Chinese bush cherry, *P. japonica* Thung., wild goose plum, *P. hortulana* Bailey, and almond, *P. communis* Arcang. He considered the wild black cherry, *P. serotina* Ehrh., and the beach plum, *P. maritima* Marsh., immune and reported no evident symptoms

TABLE 1

RESULTS OF INOCULATION OF ELBERTA PEACH TREES WITH BUDS FROM PREVIOUSLY INOCULATED APRICOT AND PLUM TREES

Source of inoculum	No. of peach trees inoculated	Healthy	Diseased
<i>Apricots</i>			
Jones	4	1	3
Early Horn (1)	5	1	4
Early Horn (2)	5	4	1
Reece (local seedling variety)	4	4	0
<i>Plums</i>			
Big Mack (1)	5	3	2
Big Mack (2)	5	0	4 (1 winter killed)
Duarte-Satsuma hybrid (1)	5	3	2
Duarte-Satsuma hybrid (2)	5	2	3
Climax	5	4	0 (1 winter killed)
Red Late Hardy	4	4	0
Omaha	5	5	0
Hungarian prune	5	5	0

following inoculation into wild plum, *P. americana* Marsh. Palmer and Parker (2) found diseased sour cherries, *P. cerasus* L., close to peaches and chokecherries affected with X-disease. They reported that "inoculations from affected sour cherries to peach resulted in typical peach-disease symptoms." Bodine (1) reported an estimated 100 peach trees infected with "western X virus disease" in western Colorado in 1944, and that no chokecherries were found in the immediate vicinity of the peach growing section. His survey of the nearest area where chokecherries were found revealed only healthy plants.

Since X-disease is still present and spreading in Colorado peach trees and the situation remains unchanged as

to the proximity of chokecherry trees to the peach area, other possible hosts of the X-disease were thought to exist. To test this hypothesis, buds were taken in the summer of 1946 from peach trees having the western X-disease and placed into nursery trees of several varieties of apricots growing on apricot seedling root stock and also into plums growing on peach root stock. In 1947, buds were taken from these 1946-inoculated trees and placed into small Elberta peach trees. Western X-disease symptoms expressed in the peach in 1948 showed that two varieties of each of the inoculated apricot and plum were carrying the western X-disease virus and none of the 40 uninoculated check trees was affected.

The results in Table 1 show that the Jones and Early Horn varieties of apricot and the Big Mack and Duarte-Satsuma plum can carry the western X-disease virus. All previously inoculated apricot and plum trees were reinoculated from peach in 1947 and the Climax plum now shows a premature yellowing and bronzing of leaves which suggest its possible infection. Inoculations from this tree, as well as other trees from which transmission was not obtained in 1947, were again made on Elberta peach in 1948. Symptoms found in other hosts require further study and will be reported later.

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Aureomycin, a New Antibiotic¹

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A new antibiotic principle active against certain viruses and rickettsia (6) and against both Gram-positive and Gram-negative microorganisms (1, 2, 5) has been isolated from the substrate of *Streptomyces aureofaciens* (4). The antibiotic has been named aureomycin from the yellow color of the parent actinomycete and the golden color of the crystalline antibiotic.

Aureomycin is a weakly basic compound which contains both nitrogen and nonionic chlorine. Aureomycin when treated with alcoholic ferric chloride gives a greenish-brown color by reflected light and reddish color by transmitted light. The crystalline free base has the following properties: m.p., 168–169° C (uncorr.); $[\alpha]_D^{25}$, –275.0 (methanol); solubility in water, 0.5–0.6 mg/ml at 25° C; very soluble in the Cellosolves, dioxane, and Carbitol; slightly soluble in methanol, ethanol, butanol, acetone, ethyl acetate, and benzene; insoluble in ether and petroleum ether; very soluble in aqueous solution above pH

¹ This work was initiated and directed by the late Dr. Y. SubbaRow, and by Dr. J. H. Williams.

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8.5; analysis: C, 54.56; H, 5.34; N, 5.77; Cl, 7.16; O, 21.17 (by diff.); mol. wt., 508 (3).

Aureomyein forms a hydrochloride with these properties: decomposes above 210° C; $[\alpha]_D^{25} = -240.0$ (water); approx. solubility in water, 14 mg/ml at 25° C; pH of aqueous solution, 2.8–2.9; analysis: C, 51.84; H, 5.24; N, 5.46; total Cl, 13.27; ionic Cl, 6.69; O, 24.19 (by diff.). The rhomboid crystals have a refractive index of 1.700 ± 0.005 . The acute angle is $80 \pm 5^\circ$.

In 0.1 N hydrochloric acid, aureomyein shows absorption maxima at 230, 262.5, and 367.5 m μ . In 0.1 N sodium hydroxide the maxima are at 255, 285, and 345 m μ .

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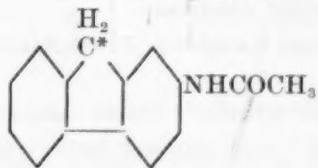
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2-Acetylaminoo-9-C¹⁴-Fluorene¹

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Since it was demonstrated by Wilson, DeEds and Cox (4) that 2-acetylaminofluorene causes a wide variety of cancer in rats, this compound has become of increasing importance in experimental cancer research (1–4). Present chemical methods are successful in accounting for only about one-third of the substance administered (3). With the hope of completely elucidating the mode of action of 2-acetylaminofluorene we have synthesized it with radioactive carbon-14 in the 9-position in the molecule.



Measurements were made with a Geiger tube having a window 4–5 mg/cm² and at a distance of 1½".

The following equations give the yields and number of counts per minute at each step for a 22 mg/cm² sample from 2 mc of BaC¹⁴O₃ and 11.5 gm of 2-iodobiphenyl.

2-iodobiphenyl	$\xrightarrow{87\%}$	2-biphenylmagnesium iodide	$\xrightarrow{60\%}$	C ¹⁴ O ₂
20,897 cpm	88%	24,872 cpm	70%	
2-C ¹⁴ -biphenylcarboxylic acid	$\xrightarrow{23,630 \text{ cpm}}$	$\xrightarrow{20,969 \text{ cpm}}$	$\xrightarrow{90\%}$	9-C ¹⁴ -fluorenene
9-C ¹⁴ -fluorene	79%	21,341 cpm		$\xrightarrow{24,832 \text{ cpm}}$
2-amino-9-C ¹⁴ -fluorene	84%			$\xrightarrow{\text{2-acetylaminoo-9-C}^{14}\text{-fluorene}}$

¹ This study was supported by research grant C341 from the National Cancer Institute of the U. S. Public Health Service.

² We wish to thank E. F. Williams, of the Stamford Laboratories, American Cyanamid Company, for the crystal analysis, and L. M. Brancone and staff for the microanalyses.

The metabolism of the radioactive compound is being studied by H. P. Morris, of the National Cancer Institute, and the results will be reported in a subsequent publication.

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Experiments in Crossing

Aedes (Stegomyia) aegypti Linnaeus and *Aedes (Stegomyia) albopictus* Skuse¹

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In 1937, Toumanoff (4) reported a series of crosses made between the two species of mosquitoes, *Aedes aegypti* and *Aedes albopictus*. In two trials he had two successful crosses of *albopictus* females and *aegypti* males. The offspring resembled *albopictus*. The F₁, F₂, and F₃ generations from these crosses also resembled *albopictus*. In four trials with *aegypti* females and *albopictus* males he had only one success, the offspring and F₂ generation resembling *aegypti*. Later (5) he reported five more crosses of *albopictus* females and *aegypti* males, two of which were successful, the F₁ again resembling the female parent. Hoang-Tich-Try (2) also reported four attempts at crossing *albopictus* females and *aegypti* males; two of the trials were successful, the F₁ resembling *albopictus*. He did not succeed in getting an F₂ generation. Edwards (1) comments on this work, suggesting the desirability of more detailed morphological studies of the crosses.

In 1944, Johannes Bauer tried to confirm this work, using colonies of *A. aegypti* and *A. albopictus* which had been maintained in the New York Laboratories of the International Health Division of The Rockefeller Foundation for several years. The origin of these colonies is not known. It was considered possible that, in the course of innumerable transfers of eggs and larvae, some mixing of the two species might well have occurred from time to time. Evidence of this was obtained, for upon examination of a large number of specimens from the cage of either colony, an occasional member of the other species would be found. Consequently, it can be suggested that neither of the lines was necessarily "pure." After preliminary trials, Dr. Bauer turned the project over to the

¹ Work conducted under the auspices of U. S. Naval Medical Research Unit No. 2 in the Laboratories of the International Health Division of The Rockefeller Foundation, New York. The Navy Department does not necessarily endorse the views set forth in this paper.

² The authors were formerly with NAMRU No. 2.

present authors. Unfortunately, in the limited time between changes in military assignments, only the brief observations below could be made.

Tests were carried out in an insectary with an average temperature of 75° F. The mosquitoes were placed in cages with two layers of screening $\frac{1}{2}$ " apart, with the front opening covered by heavy muslin cloth. Sugar water was kept in the cages, and every third day a chick was introduced into each cage to provide a blood meal. Eggs were placed in containers in screened cages for hatching and the rearing of larvae. Each pupa was removed and put into a separate test tube, and each adult transferred to a separate dry tube as it emerged. The

The experiments are summarized in Table 1. The *albopictus* females of trial A did not feed readily on blood, while the *A. aegypti* females in trial B took blood readily. Sperm was found in the spermatheca of only one of 24 *albopictus* females (trial A, group 3) dissected, although copulation had been observed. In group 2 of trial B, copulation was observed and of three *aegypti* females examined on October 17, one had sperm in the spermatheca, although no eggs were hatched. All of several *aegypti* females from group 4 of trial B, examined on October 12, had sperm in their spermathecae.

All of the offspring, including the F_2 generation of group 1, trial B, resembled *A. aegypti* in every detail. The first adult F_2 were observed on October 17, but the experiment had to be terminated at that time.

It is noteworthy that in the experiments of Toumanoff and of Hoang-Tich-Try, as well as in our own tests, offspring of the crosses have resembled the female parent. In our work reported above, this resemblance held true down to the finest morphological details of larvae and adult mosquitoes which it was possible for us to check.

It is difficult to explain these results on a genetic basis. One possibility is that fertilization by the male of the other species was not a true fertilization, but served to stimulate parthenogenetic development of the ovum. Be this as it may, both male and female offspring were obtained.

It is interesting that Summers Connal (3) working on variations observed in *A. aegypti* in Lagos, Nigeria, has noted an extensive range of color variations (the lyre pattern remaining constant). The possibility that *A. aegypti* will cross with closely related species in nature is suggested.

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Effectiveness of Vitamin P Compounds in Counteracting Anticoagulant Action of Dicoumarol

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Campbell (4) and Overman, et al. (8) demonstrated in the rabbit that 2-methyl-1, 4-naphthoquinone counteracted the action of dicoumarol. Overman, et al. (8) also reported the ability of ascorbic acid to reduce the hypoprothrombinemic response to dicoumarol. Later, this Wisconsin group (1) found that dicoumarol increases the excretion of ascorbic acid in the rat.

males and females to be introduced into cages were routinely checked under a low-power microscope by two observers.

A binocular dissecting microscope was used to check distinguishing markings of the offspring of the crosses. The pattern on the mesonotum, the sides of the thorax, the legs, the abdomen, the head, and the palpi was carefully examined. *A. aegypti* has a characteristic lyre pattern and *A. albopictus* a broad central band on the mesonotum. These are the principal distinguishing marks. The patterns of silver scales on the occiput and on the sternopleura and mesepimeron are also different. Comb-scale characters of the larvae were checked. Male terminalia were dissected out and examined. Particular attention was paid to the morphology of the ninth tergite, which is markedly different in the two species.

Experiments were started on August 5, 1944, and terminated on October 17, 1944.

Since vitamin P compounds have been recommended as adjuncts in the clinical use of dicoumarol (5), it seemed important to determine any possible interaction between

The significance of the physiological antagonism of dicoumarol and vitamin P compounds is unknown; however, a similar antagonism in bacteriological systems has

TABLE I
PROTHROMBIN TIMES IN RATS UNDER DICOUMAROL TREATMENTS*

D	D	D	D	D	D	D	D	D	D	D
M	H	M	R	R	M	C	C	C	C	AA
1. 9'	6'44"	9'33"	12'38"							
2. 15'15"	7'1"	14'51"	10'24"							
3. 10'46"	5'22"	4'35"	13'2"							
4. 11'51"	8'22"		5'38"	8'16"						
5. 14'3"	5'42"		7'33"	3'21"						
6. 12'33"	6'40"		9'21"	7'31"						
7. 11'16"	6'16"				5'21"	4'41"				
8. 5'4"					4'2"		2'26"	47"		

* Abbreviations used are: D—dicoumarol; M—menadione; H—hesperidin; R—rutin; C—catechin; AA—ascorbic acid.

the two. Rats (250–300 gm in weight) were used in accordance with the technique of Overman, *et al.* (7). The chemicals under test mixed in cottonseed oil were administered orally on three successive days with the prothrombin time being determined 4 hours after the last dose. Five rats were in each series; dosages were as follows: dicoumarol, 40 mg/kg; vitamin P compound, 80 mg/kg; ascorbic acid, 80 mg/kg; Menadione, 3.2 mg/kg. Results are recorded as average values for each series. Prothrombin times were determined by the method of Campbell, *et al.* (3). From these findings, it is apparent that D-catechin and rutin counteract dicoumarol while hesperidin does not. Ascorbic acid counteracts dicoumarol and acts synergistically with D-catechin in this respect.

Thus, the synergism of ascorbic acid and the vitamin P compounds is found in at least three systems: (1) antihyaluronidase action (2); (2) antioxidant action for autoxidation of adrenaline (9); (3) counteraction of hypoprothrombenemia produced by dicoumarol.

been reported (6). It seems logical that the mechanism controlling hemorrhage in all its phases would be interrelated. One of these mechanisms would be reflected in prothrombin times.

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Effect of *p*-Chlorophenoxyacetic Acid on the Vitamin C Content of Snap Beans Following Harvest

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Attention is being directed toward the effect of plant growth regulating substances on chemical changes that occur in fruits, leaves, and storage organs of plants after they are harvested. Some results of this research have been reported (2, 4, 6).

The vitamin C content of snap bean fruits (pods) increases as they develop, reaches a maximum as they attain full size, then decreases, regardless of whether the pods

are harvested at this stage of development or left on the plant to mature (1, 5).

In extending research in this field, experiments were made to determine the effect of *p*-chlorophenoxyacetic acid on the vitamin C content of bean fruits of marketable size. Bean plants (Black Valentine, Augrow strain) were grown in a greenhouse. When the largest fruits first attained a size acceptable for commercial use, water mixtures containing various amounts of *p*-chlorophenoxyacetic acid and 1% of Tween 20¹ were sprayed on the attached fruits. Concentrations of the acid used were: 0, 50, 250, 500, and 1,000 ppm.

Samples for vitamin analysis consisted of 6 to 10 replicates of 50 gm each, and values reported are the averages of these replicates. All results are reported on the basis of fresh weight at the time of analysis. The

¹ A sorbitol derivative used as a solubilizer and supplied by the Atlas Powder Company of Wilmington, Delaware.

vitamin C was extracted by the method of Loeffler and Ponting (3) and determined in a photoelectric colorimeter. Compensation for turbidity was applied when necessary. Tests with *p*-chlorophenoxyacetic acid and Tween 20 in water showed that the acid and detergent did not influence the vitamin C determinations.

Four days after treatment the fruits were still in a good marketable condition. There was no statistically

TABLE I
EFFECT OF PREHARVEST TREATMENTS WITH *p*-CHLOROPHOXYACETIC ACID (400 ppm) ON THE VITAMIN C CONTENT OF SNAP BEAN PODS DURING STORAGE PERIODS IMMEDIATELY FOLLOWING HARVEST

Storage period (days)	Av. vitamin C content (mg/100 gm of tissue)		Percent decrease in vitamin C content		Percent moisture	
	Untreated	Treated	Untreated	Treated	Untreated	Treated
<i>Greenhouse—treated July 8, harvested July 12, 1948*</i>						
0	17.6	22.2	...	...	87.8	90.3
1	13.5	21.8	23.3	1.8	88.3	90.5
2	11.7	20.6	33.5	7.2	87.6	89.5
3	11.2	22.0	36.4	0.9	88.1	88.6
4	11.0	19.6	37.5	11.7	87.5	89.9
<i>Greenhouse—treated July 15, harvested July 19†</i>						
0	23.4	24.0	...	...	86.7	90.5
1	17.8	21.8	23.9	9.2	86.9	87.4
2	16.9	21.1	27.8	12.1	84.7	87.9
3	15.4	19.1	34.2	20.4	86.0	86.9
4	13.6	19.7	41.9	17.9	85.8	85.2
<i>Field—treated August 5, harvested August 9‡</i>						
0	26.1	25.2	...	...	91.0	91.7
1	22.6	24.6	13.4	2.4	90.5	90.9
2	19.7	23.7	24.5	6.0	89.2	90.1
3	16.7	22.7	36.0	9.9	88.3	88.1
4	17.8	24.3	31.8	3.6	85.6	89.1
7	15.6	27.2	40.2	+7.4	84.1	82.9
9	12.6	22.2	51.7	11.9	81.9	83.7

* Difference required for significance: 5% level, 1.2 mg; 1% level, 1.6 mg.

† Difference required for significance: 5% level, 1.32 mg; 1% level, 1.75 mg.

‡ Difference required for significance: 5% level, 2.03 mg; 1% level, 2.68 mg.

significant difference between the vitamin C content of untreated fruits and those sprayed with various amounts of the growth regulator.

Additional experiments were made to determine the effect of *p*-chlorophenoxyacetic acid on the vitamin C content of fruits of snap beans during a storage period beginning immediately after they were harvested. When about a third of the fruits on snap bean plants grown in a greenhouse had reached marketable size, they were sprayed with a water mixture containing 400 ppm of *p*-chlorophenoxyacetic acid and 1% of Tween 20. Untreated plants served as controls. After 4 days all those

of a marketable size were harvested and spread out separately in a layer (1 to 2 fruits thick) in a room where the temperature varied between 74° and 76° F.

The vitamin C content of the untreated fruits decreased by 37.5% during the 4 days immediately following harvest (Table 1). In contrast, that of treated ones decreased by only 11.7%. At the end of the storage period, treated fruits contained 78% more vitamin C/100 gms of tissue than did the untreated ones, a highly significant difference.

The above greenhouse experiment was repeated. During storage, the vitamin C content of untreated fruits decreased by about 42% during the 4-day period, while that of treated ones decreased only 18% during the same period of time, a highly significant difference (Table 1). At the end of the storage period the treated fruits contained approximately 45% more vitamin C than did the untreated ones.

In another experiment, snap beans were planted under field conditions during the latter part of June 1948. By the first week of August the plants had developed a full crop of fruit, most of which had just reached marketable size. A water mixture containing 400 ppm of *p*-chlorophenoxyacetic acid and 1% of Tween 20 was sprayed on the fruits. There were 12 rows of plants in the field. Each row was divided equally, and alternate ends were treated or left untreated.

Four days after treatment all fruits were harvested and handled as previously described. The vitamin C content of untreated ones decreased 31.8% during the first 4 days' storage, that of treated ones only 3.6%, a highly significant difference. After 9 days of storage, the treated fruit contained 76% more vitamin C than did untreated ones.

In both greenhouse and field experiments it was observed that the mixtures of *p*-chlorophenoxyacetic acid checked the growth of fruits that were partially developed at the time of treatment. There was no apparent effect on the size or yield of fruits sprayed when they had attained a size commonly used in the marketing of snap beans.

From this work it is evident that the use of a water mixture of *p*-chlorophenoxyacetic acid and Tween 20 resulted in the maintenance of a relatively high vitamin C content in bean pods following harvest. Further field tests are necessary to determine if this effect is of practical value.

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A Quantitative Hardness Tester for Food Products¹

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A pressure-hardness tester has been designed by the writer and fabricated by machinists of the Division of Industrial Research to supply a quantitative method for testing hardness of fruits and other food products, replacing the qualitative "thumbnail" or "finger pres-

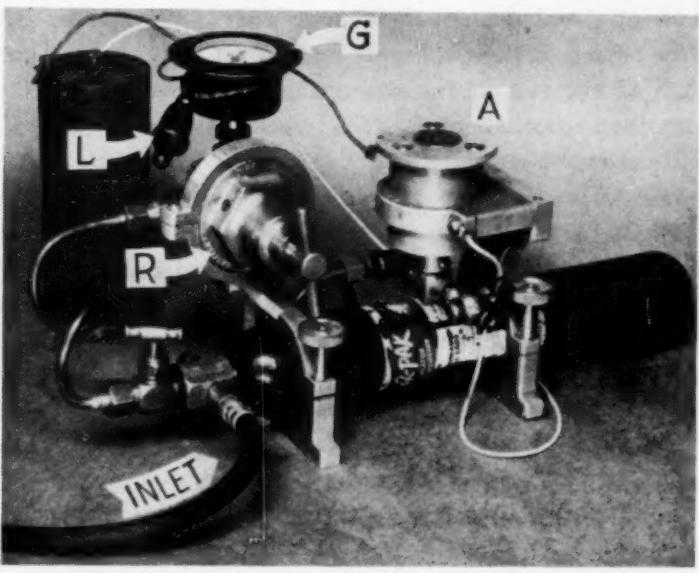


FIG. 1. Photograph of a quantitative hardness tester. Small tank not necessary when tester is connected to external source of gas pressure. Corresponding parts lettered as in Fig. 2.

sure" method. At present the device (Fig. 1) is being used to test hardness of pears in conjunction with a research project jointly sponsored by the Northwest Canners Association, Washington State Soft Fruit Commission and the Division of Horticulture, State College of Washington.

The principle of the tester is the determination of that gas pressure necessary to force the blunt end of a piston a very small but fixed distance into the test material.² The tester now in use forces a rounded brass tip 5/32" in diameter 1/32" into the pear. The top plate serves both as a stop, restricting penetration to 1/32", and as an electrical contact, completing a circuit which lights an indicator lamp when maximum penetration is reached. Pressures found necessary to effect this penetration into normal green pears have been observed to vary from 50 to 65 pounds per square inch. Abnormally hard pears were found to test above 65. Tips of other sizes and penetrations of different depths may be used for other food

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² A tester utilizing mechanical pressure from a spring was also designed and may be fabricated for later work. The writer is grateful to Prof. N. S. Golding for supplying a metal hypodermic cylinder body and piston and for suggestions concerning its use.

products. Any convenient and suitable gas source may be used, such as compressed air or nitrogen.

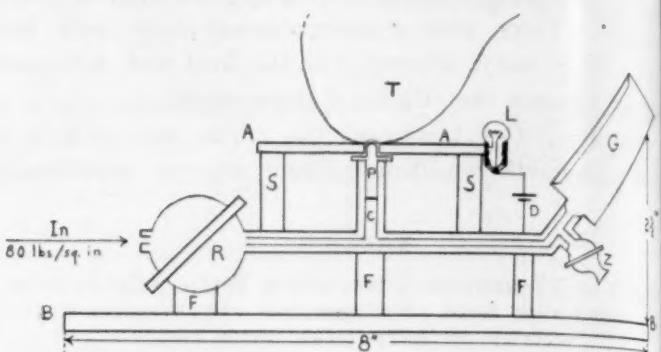


FIG. 2. Sketch of device shown in photograph. A—top plate; B—base plate; C—cylinder; D—dry cell battery; F—metal frame; G—pressure gauge; L—indicator amp; P—piston; R—regulator valve; S—insulated support; T—test fruit; Z—release petcock.

Fig. 2 shows a simplified sketch of the tester, illustrating its basic operating principles. Future models will be constructed from this design.

No injury to the fruit is apparent or expected from this test. Pears are held firmly against top plate during the test, a barely visible indentation being the only effect.

The Properties of the Enzyme-Substrate Compounds of Horse-Radish and Lacto-Peroxidase¹

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Peroxidases are iron-containing enzymes which, on the basis of both spectroscopic and magnetic susceptibility data, form definite chemical compounds with their substrate, hydrogen peroxide. These enzyme-substrate compounds cause the very rapid oxidation of oxidizable substances (acceptors) such as ascorbic acid, pyrogallol, etc. One type of peroxidase is widely distributed in plants and is usually prepared from horse-radish root (horse-radish peroxidase). Another type is found in milk and is called lactoperoxidase. The pioneer work of Keilin and Mann (10) on horse-radish peroxidase and Theorell's (16) purification and extensive studies of both horse-radish and lactoperoxidase now make it possible to study in detail the properties of the several compounds which these enzymes form with hydrogen peroxide and the mechanism by which these compounds oxidize acceptors.

¹ The horse-radish peroxidase, lactoperoxidase, and cytochrome C preparations used in these studies were generously supplied by Hugo Theorell and K. G. Paul. Many thanks are due to H. Theorell, D. Keilin, and E. F. Hartree for their criticism and advice in these researches. A special acknowledgment is made to the memory of Glenn Millikan, who greatly stimulated this development of the rapid-flow method for studies of enzyme-substrate compounds.

² John Simon Guggenheim Memorial Fellow 1946-1948; present address: Johnson Research Foundation, University of Pennsylvania, Philadelphia 4, Pennsylvania.

Theories (12) dating from 1913 have postulated that enzyme reactions involve enzyme-substrate compounds, and now these studies (4) give direct records of their reactions. Direct evidence of these chemical compounds of enzyme and substrate clearly shows that short-range, not long-range, forces are required for the action of these enzymes. The possibility that the long-range forces postulated by Rothen (14) play any part in these enzymatic reactions is very remote.

When the iron atom of horse-radish peroxidase combines with hydrogen peroxide, three distinct colored compounds are formed: green (I) (18), pale red (II) (10), and bright red (III) (10). All of them rapidly disappear when an oxidizable substance like ascorbic acid is added, with the result that the free enzyme and oxidized acceptor are obtained. Here studies have been made to show which of these three enzyme-substrate compounds are involved in the enzymatic activity of peroxidases and how the active complex reacts with the acceptor molecule.

These color changes are so rapid that a special method is needed, not only to measure the rates of formation and disappearance of the compounds, but also to obtain their absorption spectra. Various improvements (5) of the flow method of Hartridge and Roughton (9) and Millikan (15) now permit studies of the reaction kinetics and the absorption spectrum of an unstable enzyme-substrate complex that has a half-life of only several milliseconds and a molar concentration as small as 1×10^{-6} .

The spectra of the primary and secondary enzyme-substrate complexes. There are two striking features of the combination of these enzymes with their substrates; first, the brown enzyme solution becomes green, and secondly, this change appears to occur instantaneously. Theorell (18) first saw this reaction occur upon the addition of hydrogen peroxide to horse-radish peroxidase, and in these researches a similar lactoperoxidase-hydrogen peroxide complex has been found. In addition, a green primary hydrogen peroxide complex of the related enzyme, catalase, has been found (6). These three enzymes can also combine with substituted peroxides (methyl [CH_3OOH] or ethyl [$\text{C}_2\text{H}_5\text{OOH}$] hydrogen peroxide), and here again green primary complexes are found. In all nine cases studied, enzyme and substrate were found to combine in very rapid reactions.

By using the rapid flow apparatus, quantitative data on the absorption spectra of these green primary compounds have been obtained. The addition of peroxide to these enzymes causes a very large decrease in the intensity of their major absorption band as shown by the shift from curve A to curve I of Fig. 1. The spectra of the nine primary compounds studied are very similar, and it is concluded that they all involve the same type of iron-peroxide bond. From Theorell's studies of the magnetic susceptibility of related peroxidase compounds (peroxidase fluoride) (17), it is probable that the iron atoms of these primary enzyme-substrate compounds are bound by essentially ionic bonds in the primary complexes.

In peroxidases, these primary peroxide complexes rapidly shift into a red secondary form in about 0.1 sec

under these conditions. These red forms were first seen and their visible absorption bands were measured by Keilin and Mann (10) using horse-radish peroxidase and by Theorell and Åkeson (19) using lactoperoxidase. Curve II of Fig. 1 shows that the absorption band of the secondary complex differs considerably from that of the primary complex. Curve II closely resembles the absorption band of horse-radish peroxidase-cyanide which has been found by Theorell to have covalent bond-

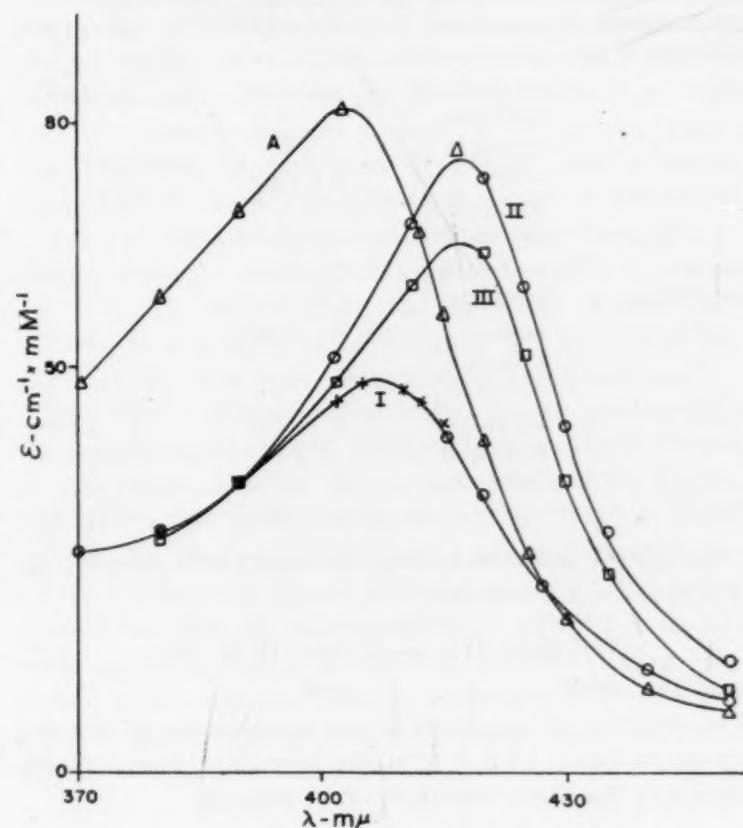
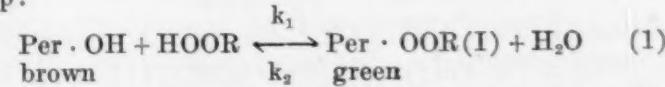


FIG. 1. The Soret bands of free peroxidase (A) and peroxidase combined with hydrogen peroxide to form the primary (I), secondary (II), and tertiary compounds (III). Complex I is very unstable and the points on this spectrum were measured by means of the rapid-flow apparatus. Under proper conditions, Complex II is relatively stable and both the rapid-flow apparatus and the Beckman spectrophotometer were used to measure its spectrum. Complex III forms in the presence of a large excess (10- to 100-fold) of hydrogen peroxide; its spectrum was measured in the Beckman spectrophotometer.

ing. Thus it is probable that these secondary peroxidase-peroxide complexes also have covalent bonding. These data show that the substrate can combine with the enzyme so as to alter profoundly the absorption spectrum and the nature of the chemical bonds in the enzyme.

The reaction kinetics of the primary and secondary complexes. By timing the rate of formation of the primary complexes in the rapid-flow apparatus, the reaction-velocity constants for the union of peroxidase with peroxide molecules have been studied. In this very rapid reaction, the hydroxyl group bound by ionic bonds to the iron atom of peroxidase (16) is replaced by the peroxide group:



R may be H- (18), CH₃- or C₂H₅-, and the values of k,

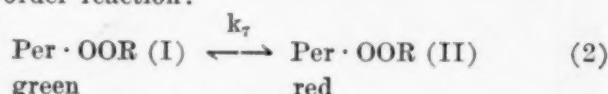
for these substrates are given in Table 1. These enzymes combine with their substrates at about the same speed as muscle hemoglobin combines with oxygen (13).

ticular experiment. The quantity $t_{1/2}$ is the time from $t = 0$ until the concentration of complex II has fallen to half its maximum value. Thereby the enzyme-sub-

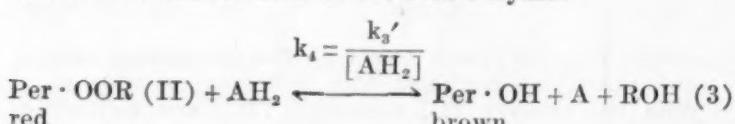
TABLE 1
REACTION VELOCITY CONSTANTS FOR EQUATIONS 1, 2, AND 3

Enzyme	Substrate	$k_1 \text{ (M}^{-1} \times \text{sec}^{-1}\text{)}$	$Km_2(M)$ $k_7(\text{sec}^{-1})$ $k_3(\text{sec}^{-1})$			$k_4(M^{-1} \times \text{sec}^{-1})$ for ascorbic acid (pH 7.0)	$k_4(M^{-1} \times \text{sec}^{-1})$ for pyrogallol (pH 7.0)
			for zero acceptor concentration				
Horse-radish peroxidase	hydrogen peroxide	1×10^7	1.5×10^{-8}	4.0	0.05	2,800	2.1×10^5
	methyl-hydrogen peroxide	1.5×10^6	3×10^{-7}	4.0	0.03	2,800	2.1×10^5
	ethyl-hydrogen peroxide	3.6×10^6	....	4.0	0.02	2,200	1.8×10^5
Lacto-peroxidase	hydrogen peroxide	2×10^7	1×10^{-8}	4.0	0.03	5,400	7×10^6
	methyl-hydrogen peroxide	6×10^6	2×10^{-8}	4.0	0.03	2,700	....
	ethyl-hydrogen peroxide	2×10^6	2×10^{-8}	4.0	0.02	2,100	....

Complex I is spontaneously converted into complex II in a first-order reaction:



The oxidation reaction occurs on combination of the acceptor molecule (AH_2) with the secondary complex and results in the liberation of the free enzyme:



The velocity constant (k_4) for the reaction of complex II with acceptor is here taken as a measure of the enzyme activity (see Table 1). The values of k_7 given in the table increase greatly when an acceptor is added. Therefore, the transition from complex I to complex II is not a rate-determining step in peroxidase kinetics. Only the combination of enzyme and substrate and their reactions with the acceptor are rate-determining steps in accordance with previous data (4). When $[AH_2] = 0$, complex II nevertheless spontaneously decomposes in a first-order reaction of rate k_6 (see Table 1).

In these studies, the utilization of peroxide by the enzyme system can be readily measured from the graph of the concentration of complex II as a function of time as shown in Fig. 2. Complete solutions of the equations for peroxidase kinetics (4) have shown that a simple relation exists between k_4 and values readily measured from the kinetics of complex II:

$$k_4 = \frac{[\text{HOOR}]}{[\text{Per} \cdot \text{OOH - II}] [\text{AH}_2]_{\text{init}}} \text{ M}^{-1} \times \text{sec}^{-1} \quad (4)$$

where $[HOOR]$ and $[AH_2]$ are initial concentrations ($[AH_2] > [HOOR]$) and $[Per \cdot OOH (II)]$ is the maximum concentration to which complex II rises in the par-

complex is used as a spectrophotometric indicator of its activity. This method permits studies of enzyme activity in the presence of substrate concentrations which are much less than those measurable by ordinary techniques. Thus enzyme inactivation caused by excessive substrate concentrations is avoided.

The values of k_4 given in Table 1 show that, usually, the reaction of enzyme and substrate is considerably more rapidly than the reaction of complex II with the acceptor. This is not a general rule; the reaction of complex II of lactoperoxidase and hydrogen peroxide with hydroquinone is nearly as rapid as the combination with hydrogen peroxide.

The values of k_4 show that lactoperoxidase is a more active enzyme with these two acceptors than is the plant enzyme. In addition, the milk enzyme combines more rapidly with hydrogen peroxide. These differences may be attributed to differences between the protein parts of these two enzymes.

In general, the peroxidase complexes formed from the substituted peroxides react just as rapidly with acceptors as do the complexes formed from hydrogen peroxide. The same result was obtained in the reactions of the catalase-peroxide complexes with alcohols and other substances (6). The rate of formation of the primary complexes, however, decreases somewhat with the substituted peroxides, possibly owing to a steric effect. This effect is much less with peroxidases than with catalases (6).

Fig. 2 illustrates the effect of using three different substrates upon the kinetics of complex II. With hydrogen peroxide, k_1 is largest, and the concentration of complex II rises to very nearly its saturation value. Because nearly all the enzyme is in the form of this reactive complex, the oxidation of ascorbic acid is rapid, and consequently the hydrogen peroxide is consumed in about two

seconds. Since methyl hydrogen peroxide combines more slowly with peroxidase, the concentration of complex II rises to a smaller value in this test, and the consumption of the peroxide requires a longer time. A similar effect is observed with ethyl hydrogen peroxide. But in all three cases, the values of k_4 calculated from equation 4 are nearly the same ($2,800, 2,800$, and $2,200 \text{ M}^{-1} \text{ sec}^{-1}$;

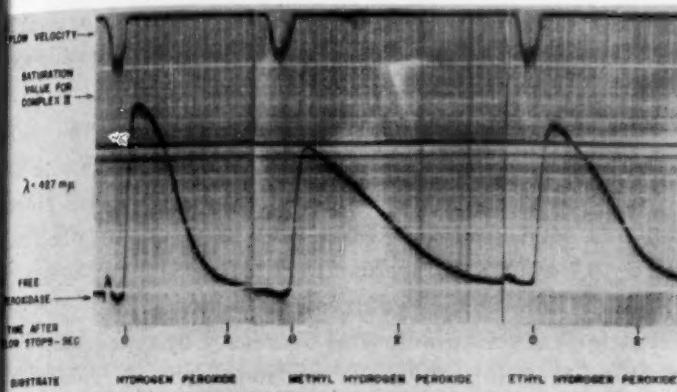


FIG. 2. Illustrating the use of the rapid-flow apparatus in the measurement of the rapid formation (fast rise of traces) and disappearance (slower fall of traces) of the enzyme-substrate complexes of horse-radish peroxidase ($2.9 \times 10^{-6} \text{ M}$) caused by reactions with hydrogen peroxide ($3.6 \times 10^{-6} \text{ M}$), methyl hydrogen peroxide ($4.2 \times 10^{-6} \text{ M}$), and ethyl hydrogen peroxide ($3.2 \times 10^{-6} \text{ M}$) in the presence of ascorbic acid ($40 \times 10^{-6} \text{ M}$). These three enzyme-substrate complexes are here used as spectrophotometric indicators of the peroxide concentration; the velocity of their reaction with ascorbic acid is calculated by equation 5. The results are given in Table 1.

see Table 1). The earlier conclusion of Wieland and Sutter (20) that the activity of horse-radish peroxidase with ethyl hydrogen peroxide is $\frac{1}{2}$ that with hydrogen peroxide is apparently incorrect.

In the absence of added acceptor, the very high affinity of the enzyme for its substrate can be demonstrated; Table 1 lists as K_m the concentrations of peroxide which give the half-saturation value of complex II. These concentrations are much less than those required to half-saturate muscle hemoglobin with oxygen and about as small as the concentration of oxygen estimated to give half-saturation of the respiratory enzyme (13).

With horse-radish peroxidase, but not with lactoperoxidase, the values of k_7 and k_8 can be reduced more than tenfold by repeated additions of an equivalent of peroxide. But k_8 has never been reduced to zero; the enzyme-substrate compounds of both peroxidase and catalases slowly undergo "spontaneous" decomposition (whose mechanism is not understood) into the free enzyme.

The reversible decomposition of the enzyme-substrate complexes (k_9 of equation 1) does not appear to play an important role in the reaction kinetics; in fact, final proof of the existence of k_9 is lacking. Hence, the rapidly reversible combination of enzyme and substrate pictured in the theory of Michaelis and Menten (12) is not characteristic of these enzymes.

The relation between the enzyme-substrate bond and the activity. In peroxidase, the covalent secondary complex must be formed before oxidation of the acceptor oc-

curs and the enzyme is liberated from the complex. But in catalases, the primary complex with presumably ionic bonds appears to react directly with the acceptor; the enzyme is liberated from the primary complex without the formation of a measurable amount of a secondary complex of the type that peroxidase forms. This fundamental difference in the mechanism of catalase and peroxidase reactions may ultimately be resolved by further search of an undiscovered covalent complex in catalase reactions. Nevertheless, based on the nine similar primary complexes of catalase, horse-radish peroxidase, and lactoperoxidase, which surely have the same bond type (probably ionic), there is support for the generalization that this type of compound of enzyme and substrate forms first and more rapidly than the covalent compound.

None of these oxidations caused by these hematin-peroxide complexes can be inhibited by carbon monoxide (6, 7, 8, 10), and therefore, the iron atom of these peroxidases is concluded to be trivalent and to remain trivalent in reactions with the substrates and acceptors.

The relation between heme-linked groups and activity. By a variation of the pH, linkages between the iron atom of peroxidases and the protein molecule can be altered, and their effect upon peroxidase activity may be determined. In alkaline solution above pH 9, peroxidase acquires a covalently bound hydroxyl group (17). Under these conditions the enzyme-substrate complexes do not form, and the enzyme is inactive, the effect being very similar to that observed when cyanide is bound to the iron atom of peroxidase by covalent bonds. Apparently the exchange reaction of equation 1 between the hydroxyl group bound by ionic bonds and the peroxide group is inhibited when the hydroxyl group is bound to the iron atom of peroxidase by covalent bonds.

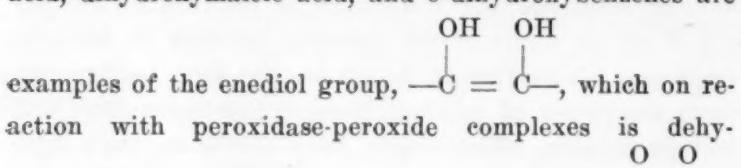
The dissociation constant (K_m) and reaction kinetics of the primary and secondary complexes of horse-radish peroxidase are found to be practically unchanged from pH 8.8 to 3.6. This is in accordance with studies of this particular peroxidase preparation which shows no changes of heme linkage in this pH region. Below pH 3.6, a change of heme linkage of pK 3.5 is found by direct spectrophotometric studies and by the effect of pH upon the dissociation constant of the horse-radish peroxidase fluoride and cyanide compounds.

In accordance with these data, the values of k_4 for the reaction of complex II with a number of acceptors show no systematic variation in the region pH 3.6 to 6.7. In general, nearly constant activity is found in this region, for example, in the case of hydroquinone, guaiacol, and pyrogallol. Where changes of k_4 are observed, changes in the course of the oxidation are also observed (leucomalachite green).

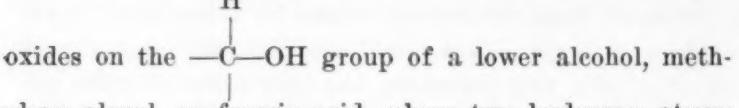
As a consequence of these experiments, the previous concept of sharp "pH optima" for peroxidases and catalases may be discarded. When the actual reaction velocity constants involved in the enzymatic activity are measured directly from the kinetics of the enzyme-substrate complex, errors caused by enzyme inactivation, by partial saturation of the enzyme with substrate, or by

a variable lag between the disappearance of substrate and the appearance of a colored reaction product are eliminated. The activity is practically constant in the broad region where no changes of heme-linkages occur.

Acceptor specificity. Balls and Hale (3) generally describe peroxidase as a dehydrogenase removing two hydrogen atoms from different carbon atoms. Ascorbic acid, dihydroxymaleic acid, and *o*-dihydroxybenzenes are



drogenated to the diketo or *o*-quinone group, $-\text{C}=\text{C}-$. Such a reaction is related to the action of catalase-per-

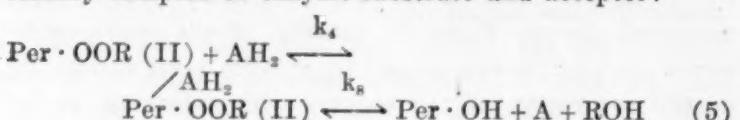


give the group $-\text{C}=\text{O}$. While catalase has been found to be highly specific for small molecules of related structure, peroxidase-peroxides oxidize a wide range of rather different substances, for example, iodide or leucomalachite green. It is clear, however, that the broader acceptor specificity of peroxidase includes reactions analogous to those of catalase except that the two hydrogen atoms are attached to different carbon atoms. Since catalase hematin is accessible only to small molecules while peroxidase hematin is accessible to rather large molecules, further analogies between catalase and peroxidase specificity are difficult to demonstrate.

The oxidation of a number of substances previously considered to be inhibitors of peroxidase activity (3), e.g., phenol, aniline, resorcinol, and phloroglucinol, can be demonstrated by these more sensitive methods.

A particularly interesting reaction is the oxidation of ferrocytochrome C by the peroxidase-peroxide complexes. Contrary to the conclusions of Altschul, Abrams, and Hogness (1), horse-radish peroxidase has considerable activity in this reaction as does lactoperoxidase. At pH 4.6, the turnover numbers of these enzymes are $k_s = 3.1$ and 2.5 sec^{-1} , respectively, as calculated from the rate of oxidation of ferro- to ferricytochrome C. In view of the acceptor specificity of peroxidase, it is more likely that the peroxidase-peroxide complex initially oxidizes the imidazole group of ferrocytochrome C and not the iron atom (see Theorell, 16).

The ternary complex of enzyme substrate and acceptor. The kinetics of oxidation of ferrocytochrome C oxidation by the peroxidase-peroxide complexes, instead of being first order as equation 3 indicates, approximate the zero order until the ferrocytochrome C concentration has fallen to a small value. These reaction kinetics suggest that the rate-limiting step is the decomposition of a ternary complex of enzyme-substrate and acceptor:



Usually k_s is fairly large—with pyrogallol it may be greater than $2,000 \text{ sec}^{-1}$. However, with ascorbic acid, k_s is roughly 20 sec^{-1} . Values for k_s in the oxidation of methanol by catalase peroxides are about 10 sec^{-1} . The unusually small value of k_s ($\sim 3 \text{ sec}^{-1}$) in the ferrocytochrome C reaction is possibly caused by the complexity of the cytochrome C molecule and the stoichiometry of the reaction. There is ample kinetic evidence for equation 5 but, as yet, no spectroscopic evidence for such a ternary complex has been obtained (see also LuValle and Goddard, 11).

Activity and oxidation-reduction potential. The velocity constant (k_4) for the reaction of complex II with acceptor molecules of different oxidation-reduction potential has been studied. First, the variation of pH from 3.6 to 6.7 causes no systematic decrease in the values of k_4 for hydroquinone, guaiacol, and pyrogallol, yet their oxidation-reduction potential decreases by 0.186 v because of this pH change (2). If hydroquinone is replaced by quinhydrone at constant pH, the value of k_4 calculated on the basis of the hydroquinone molarity is nearly constant. Thus other factors are much more important than oxidation-reduction potential in determining the value of k_4 . For example, hydroquinone and pyrogallol have about the same oxidation-reduction potential but hydroquinone reacts about 10 times more rapidly ($k_4 = 25 \times 10^6$ compared to $2.1 \times 10^5 \text{ M}^{-1} \times \text{sec}^{-1}$).

It is concluded that the rates of these biological oxidations are remotely related to the oxidation-reduction potentials of the acceptors.

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17. THEORELL, H. *Ark. Kemi. Mineral. Geol.*, 1942, **A16**, No. 3.
18. THEORELL, H. *Enzymologia*, 1941, **10**, 250.
19. THEORELL, H., and AKESON, A. *Ark. Kemi. Mineral. Geol.*, 1943, **B17**, No. 7.
20. WIELAND, H., and SUTTER, H. *Ber.*, 1930, **63**, 66.

Comments and Communications

Pressure Patterns in Bird Migration

Before I read H. Landsberg's suggestion (*Science*, December 24, p. 708) that, on migration, birds fly according to meteorological pressure patterns, I had come to a similar conclusion after an experience with the redwing (*Turdus musicus* L.). Redwings usually come from Norway to the east coast of the United Kingdom in autumn or early winter and gradually pass further south as the weather becomes colder. With the advent of warmer weather in spring, they retreat in the opposite direction. But this rule does not always hold, as is shown by a remarkable immigration which took place in February 1948 at Hill Head, Hants. The month opened with spring-like weather, alternating sunshine and showers, the wind being in the southwest. By February 7 the hazel catkins were out and the sallow buds were opening. On February 16 there was a sudden change—the weather was cold and dry with an east wind which blew for three days before shifting to the northeast. There was then a sprinkling of snow at night followed by slight snow. By next day it was freezing and more snow fell. On February 21 with the wind still northeast, there was a blizzard of snow which lasted most of the day. All through that day there was a continuous stream of small parties of redwings flying low and crossing the coast from the south. Next day, the snow lay four inches deep, a most unusual occurrence at Hill Head, and a few more redwings came in from the sea. The snow had stopped falling by that morning, and all day there were crowded parties of redwings, with a few fieldfares (*T. pilaris* L.), sheltering under the bushes in our garden.

Reference to the meteorological maps of that period shows that there was an anticyclone centered in the North Sea, with the result that snow must have fallen heavily in Scandinavia, obliterating the redwings' food supply, whereupon the birds must have taken to the air to seek fresh provender and have been carried by the wind of the anticyclonic pressure systems to Denmark, the Lowlands, and France, and thence to the south coast of England. Far from finding a new food supply, the birds had been carried helplessly along the outer edge of the pressure system, and thus remained in the area of snow precipitation, with the result that many of them died of starvation.

C. SUFFERN

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On the Carcinogenesis of 2-Substituted Fluorenes

The noncarcinogenic coal-tar hydrocarbon, fluorene, is made carcinogenic by the introduction of such groups as acetylamino, diacetylamino, amino, and nitro in the 2

position (H. P. Morris, C. S. Dubnik, T. B. Dunn, and J. M. Johnson. *Cancer Res.* 1947, 7, 730-1). In a paper dealing with a biochemical hypothesis of the genesis of cancer (L. A. Pinck, *Ann. N. Y. Acad. Sci.*, 1948, 50, Art. 1, 1-17) it was postulated that the position of the substituent rather than its chemical composition was in a larger measure responsible for the functional attribute of the carcinogen. It was indicated that other substituents in the 2 position of the fluorene molecule, having electronegativities within certain limits in the range of that of the acetylamino group, might also make those fluorene derivatives carcinogenic. From a chemical viewpoint the methylene group in the 9 position of the fluorene molecule (encircled in Fig. 1) is greatly activated by the presence of a substituent in the 2 position. This point was confirmed by work recently published.

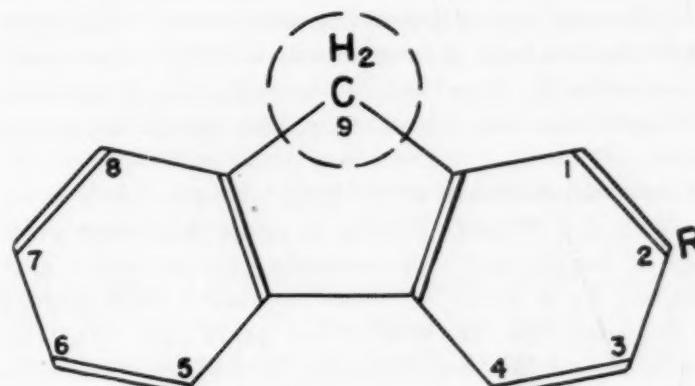


FIG. 1. A 2-substituted fluorene.

Schiessler and Eldred (*J. Amer. Chem. Soc.*, 1948, 70, 3958-9) found that 2-acetyl-fluorene is readily oxidized to fluorenone-2-carboxylic acid by the action of potassium hypochlorite at room temperature, whereas fluorene under the same conditions does not yield a trace of fluorenone. Ray, Weisburger and Weisburger (*J. org. Chem.*, 1948, 13, 655-662 reported that 9,9'-bifluoryl-2,2'-dicarboxylic amidine dihydrochloride is easily converted to the 9,9'-bifluorylidene derivative by air oxidation and that special precautions are necessary to prevent its oxidation in the course of crystallization. The chemical behavior of the above compound is quite different from that of 9,9'-bifluoryl. A change in the activity of the methylene group due to the presence of a nitro group in the 2 position of fluorene was also reported by other investigators (E. Bergmann, H. Hoffman, and D. Winter. *Ber.* 1933, 66, 46-54; A. Novelli and A. P. G. de Varela. *Ciencia E Investigacion* 1948, 82-84).

On the basis of the reactions cited above and those referred to in the cancer paper I should like to call the attention of oncologists to the very reactive nucleus of a carcinogenic fluorene, namely, the methylene group in the 9 position, and to the first step in carcinogenesis which obviously involves the oxidation of this particular group as postulated in my hypothesis.

LOUIS A. PINCK

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Oyster Mortality in Louisiana

In a recent comment (*Science*, October 29, pp. 484-485) Gunter apparently attempts to minimize the seriousness of the oyster losses in the State of Louisiana which have occurred and are continuing to occur. The use of statistics in such a connection can be very misleading without detailed study of the facts. Even though the total production remains stable or actually increases, it must be realized that this situation results from expansion of the industry through use of undeveloped grounds, of which Louisiana has an abundance, and of better utilization of producing grounds. It does not negate the fact that a continuing unexplained mortality may prevent the production from reaching even higher levels. Furthermore, once the expansion is completed, this mortality may then result in decline as the adverse factors causing this mortality continue and spread to other areas. This latter possibility has been in the minds of Louisiana oyster conservationists for some time. Because they are progressive and look into the future, they have good reason for alarm.

Conservation officials of the State have repeatedly asked the Fish and Wildlife Service to assist them with problems of unexplained and continuing severe oyster mortalities. As a result of those requests I was detailed to Louisiana for this work a few years ago. Unfortunately, the studies were discontinued abruptly because of the war. But even in this brief work, we saw sudden oyster deaths and watched many acres of oyster bottoms covered with excellent oysters change into acres of empty shells. Oystermen sustained heavily financial losses, the production of their ground dropping to zero. It cannot be denied that serious mortalities have occurred and are of great concern to the oyster industry of Louisiana. The seriousness of such losses should not be overlooked for their danger that the factor or factors bringing about these mortalities may continue to spread.

WALTER A. CHIPMAN, JR.

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Biological Education in Secondary Schools

The increase in food production which has been accomplished in spite of a shortage of labor is the result of the application of scientific principles to farming. This is modern agriculture, and it has little in common with the traditional ideas of peasant farming. The effective use of fertilizers of high yielding varieties, of chemicals which control insects, nematodes, and weeds, of better agricultural machinery, and of better agricultural practices have all contributed to making this nation a leader in agriculture. What are we doing to maintain this leadership in the future? Do we adequately acquaint the coming generations with the basic principles of biology,

chemistry, and physics upon which rests our future in agriculture?

Like so many other biologists, I have watched with apprehension the appalling lack of appreciation of the importance of the teaching of biology at the secondary school level in this country. To me it seems obvious that, if we are to keep our leading position, we will have to gear our educational system to modern agriculture. This cannot be done adequately without making biology a required subject in all secondary schools.

Other countries have long realized the importance of indoctrinating their coming generations in the principles of biology. In Holland, long a leader in the field of intensive agriculture in their home country and the tropics, every student attending secondary school receives five full years of training in zoology and botany. This has contributed much in providing the Dutch empire with a steady supply of workers necessary in all the phases of a complicated economy based on modern agriculture. Training of this sort provides a suitable basis for further specialization. In addition, it has great cultural value in that a larger section of the population obtains a better understanding of the problems which confront an agricultural economy.

In this country we could well profit by this example and embark on an educational program which will make the nation aware that our economy actually rests on biological principles. High school courses could start profitably during the freshman year with a simple course in human anatomy. Young people are very interested in themselves; hence such a course would logically serve as an introduction to biology. Gradually the student should become acquainted with other forms of life that exist in the world around us. In an age of synthetic chemicals we tend to forget that the source of energy which makes human beings go is still derived from food, for which we are dependent upon plants and animals. Courses in biology should therefore include animal and plant taxonomy, morphology, and anatomy. During the final years, when the student is acquiring knowledge of physics and chemistry, some of the principles of animal and plant physiology could be taught. This emphasizes the desirability of teaching biology as an integral part of a required course in basic science.

We are well aware that our store of scientific knowledge has increased enormously during the past decades, and one would therefore be inclined to think that teaching of basic science at the secondary school level would hopelessly overcrowd the curriculum with complicated courses. This is not necessarily so. On the contrary, we are now in a position to teach the principles and omit the frills. As Pauling has stated in the introduction of his new chemistry book: "Nevertheless, despite its growth (the) science can now be presented to the student more easily and effectively than ever before."

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In Memoriam

Wesley Clair Mitchell

1874-1948

When Wesley Mitchell started the National Bureau of Economic Research in 1920, the work and the teaching of economics were largely a speculative exercise. Concepts such as "normal value" and "marginal utility" held the center of the stage. Wesley Mitchell brought to this thinking a simple but radical program. Without minimizing the role of theory in economics, Dr. Mitchell held that it was possible to substitute fact for conjecture and tested conclusion for hypothesis. He developed what was, in my judgment, the most majestic research conception that any economist or group of economists has yet produced. By measuring and analyzing continually the central flows of our economic life, he undertook to find out "what has really happened" and "what is happening," and thus lay a foundation for the third question, "why?" No economist of our time has contributed so fundamentally to building a body of verified economic knowledge.

But the heart of my thought today is this: What did Wesley Mitchell, the man, contribute to Wesley Mitchell, the scholar?

In the social sciences the nature of the problems, the nature of the data, the less mature development of methodology, and the tremendous pressures on students to jump to conclusions, or to some special conclusion, make it inevitable that a larger share of the needed controls and defenses must exist in the character and spirit of the scholar than is the case in the physical and biological sciences. And Dr. Mitchell had those inner qualities that multiplied the value of his scholarship and enhanced its influence among all men.

Dr. Mitchell had one of the cleanest-cut, most analytical minds I have ever encountered, and a memory to match. His role was to discover truth, and its discovery remained a holy experience with him to his dying day. It was not enough to say a contribution was original or ingenious or plausible or logical. He insisted on establishing methods which would answer the ultimate question: "Is it true to life?" No matter how difficult, complicated, or costly in time and effort, Mitchell demanded the answer to that question. He was a perfectionist,—a determined, persistent, working perfectionist. The words which Dr. Arthur F. Burns, Director of Research of the National Bureau, recently used to describe the qualifications needed for

fruitful empirical research in economics were, in effect, a description of Wesley Mitchell and his steadfastness of purpose and method:

"He must have the patience to examine with meticulous care the economic coverage and representativeness of the statistics that lie at hand; the enterprise to seek out remote and inaccessible bodies of information; the imagination and technical skill to devise appropriate methods of relating, combining, reducing, or decomposing statistical observations; the personal industry or the clerical assistance to carry through these laborious operations; the common sense to make full use of nonquantitative information about commercial markets and processes; the conscience to test results repeatedly against fresh observations; the character to scrap results if error or unconscious bias is spotted; the fortitude to expose his materials and methods to the public's gaze; the wisdom to seek the help of others who might make his own best efforts obsolete."

The thing which stands out in my mind about Mitchell's work was its emphasis on quality and the thoroughness with which he did a job so that it did not need redoing by the next person who came along. The fundamental conception which permeated Mitchell's philosophy of work was precisely the conception that each man should be able to build on what went before without having to redo the entire structure. He believed and practiced the theory that the function of research people was to provide bricks for a building, and that each man should not take as his own job the building of the whole structure. To give one small example, I refer to Mitchell's little classic on index numbers. This is a subject on which a great deal has been written by a great many people. Much of the work has been more flashy than Mitchell's; yet his classic is by far the best thing available on the subject. He did a job that needed to be done, and he did it once and for all. He laid his bricks in a foundation upon which others could build firmly.

This emphasis on quality of workmanship as a prerequisite for making economics a cumulative science seems to me to be the most important element in Mitchell's methodological position.

A personal characteristic that strengthened his capacity to attain this quality was his ability to take criticism. Three years ago he told a colleague: "I hope I finish this job on which I am now working before I become too old to take criticism." I doubt whether any colleague of Mitchell's can recall when he ever took personally any criticism directed at himself; he always reached out to such criticism with eager

sympathy and an open mind. Where critical himself, he was never carpingly so, but always considered ideas and developments in their proper and therefore explanatory setting. And he expressed his own ideas with exceptional clarity and elegance. A great essayist was lost when Wesley Mitchell turned to economic research.

So far, I have been discussing chiefly Mitchell's qualities of mind and character. I turn now to his more personal qualities as a colleague who was also a delightful human being. I think first of his humility. Once, when Moore's mathematical approach to business cycles was under discussion, a colleague commented upon its originality, and Mitchell replied, "I am not so brilliant and I find my mind moves more slowly." The impression he created on this colleague was that of a man who was modest to the point of humility about the capacity of his mind to undertake ambitious flights of imagination, and therefore of his imperative need to go step by step as the data revealed one connection after another. But Dr. Mitchell's humility did not prevent his doing an artistic job of calling a man down when he needed it.

With this undue modesty about himself, Wesley Mitchell had an inveterate respect for other scholars. His humility was fused with his optimism. This optimism was partly reflected in his respect for the human mind, partly implicit in his stress on empirical investigation. A man must be a fundamental optimist to believe that human intelligence, regardless of the limitations it has shown, can be firmly counted on to add something useful; to believe that all workers in a field deserve respect because they all contribute within their capacities to the ultimate result. And a man rejects preconceived prejudices and instinctive reactions when he stresses the importance of accumulating data and relating them, item by item, to increasingly relevant hypotheses for the understanding of social processes. Such a man must believe implicitly in human responsiveness to objective knowledge. I can explain in no other way the kindly readiness that he always displayed to assist younger workers who became impatient with the recalcitrance of the data, or who lost faith in the possibility of deriving beneficial conclusions from empirical study.

In spite of the tremendous discipline he enforced on himself, Mitchell was always ready to give of his time, his thought, and his work unsparingly to others. One friend said to me on his death:

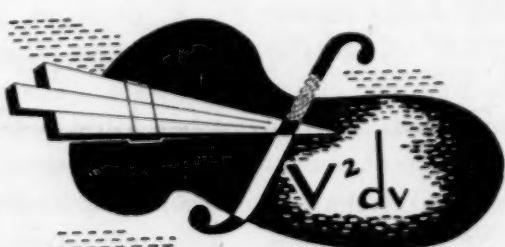
"I did not know Dr. Mitchell well, yet I deeply feel his death. This is because of his spontaneous sympathy. He was really concerned with what you were doing and thinking, and he showed it. The few times I talked with him, always briefly, left me with a kind of renewal of spirit, a kind of resistance to a feeling of futility. If these brief and casual contacts would evoke such a feeling of fellowship, how much greater must have been his influence on those who knew him more intimately. It was the warmth of his personality that left its impression on me. It is my belief that in academic circles there is a certain tendency for older men to make casual encounters an occasion for impressing their own superiority upon their juniors. Dr. Mitchell did not do that. He assumed an equality that did not exist except on one level, the level of effort and aspiration. But that is perhaps the only sound level of human footing. It is my opinion that this trait has had much to do with the character of the National Bureau."

Wesley Mitchell was a man of integrity, of enormous tolerance, and catholicity of spirit. He was a scholar with a fairness and objectivity that no one ever questioned—a human being with gaiety and an infectious sense of humor. I hope that all scientists will read the lessons of his character and spirit, along with the lessons from his mind, and thus help to keep these qualities viable.

(In these remarks, made at the memorial meeting held for Dr. Mitchell at Columbia University, December 4, 1948, I have drawn freely, without specific acknowledgment, on conversations and correspondence with my own colleagues and former colleagues and friends of Dr. Mitchell's including Anne Bezançon, Arthur F. Burns, William J. Carson, Milton Friedman, Simon Kuznets, Frederick C. Mills, Roswell C. McCrea, Robert Warren, and Leo Wolman.)

JOSEPH H. WILLITS

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Book Reviews

A text-book of mathematical analysis: the uniform calculus and its applications. R. L. Goodstein. Oxford, Engl.: Clarendon Press; New York: Oxford Univ. Press, 1948. Pp. xii + 475. \$9.00.

In presenting this rigorous book on calculus the author has attempted to avoid difficult fundamental items like the Dedekind theory of real numbers or the proof of uniform continuity of functions continuous in an interval.

The basic theory of real numbers is given in the form of a precise theory of infinite decimal fractions, culminating in the classical theorem that nests of intervals determine a number. From here the author could have proceeded in the usual way. But he wants to simplify the theory by introducing only "uniform continuity" (instead of continuity in general) and only uniform differentiability of $f(x)$ (instead of differentiability in general). This expression means that the derivative $f'(x)$ is defined in such a manner that it is uniformly continuous in the considered closed interval $[a, b]$. His definition is equivalent to the following: For every $\epsilon > 0$ there exists a $\delta > 0$ such that

$$\left| \frac{f(X) - f(x)}{X - x} - f'(x) \right| \leq \epsilon$$

If X, x are in $[a, b]$ and $0 < |X - x| \leq \delta$.

The author's procedure restricts the generality of the usual calculus somewhat. On the other hand, he is able to emphasize constructive proofs and avoids such theorems as the Heine-Borel covering theorem or the Bolzano-Weierstrass theorem. It seems therefore that his philosophy of mathematics has induced the author to develop his presentation of calculus. Whether many mathematicians will like his approach remains to be seen.

ARTHUR ROSENTHAL

Purdue University

Sequence in layered rocks: a study of features and structures useful for determining top and bottom or order of succession in bedded and tabular rock bodies. Robert R. Shrock. New York-London: McGraw-Hill, 1948. Pp. xiii + 507. (Illustrated.) \$7.50.

Sequence in layered rocks should enjoy extensive use because it brings together in very usable form a large mass of detailed information about original structures of rocks that heretofore has been widely scattered through the literature. Field men particularly will find this book a useful one to include in a limited field library.

Dr. Shrock apparently has in mind the problem that confront field geologists dealing with highly folded rocks because his avowed purpose in writing the book is to assemble information that will assist in the discrimination of tops and bottoms in folded layered rocks. Though admirable in itself, the purpose seems to understate the actual achievement of the book.

A unique and commendable feature of the book is the very extensive use of line diagrams and photographs, many of them original, over detailed descriptions of the features portrayed; so that the reader sees as well as reads about the subject simultaneously.

Approximately 60 pages are devoted to definitions and to a review of what the author terms "gross relationships." This latter feature sets forth the author's views on such basic concepts as superposition, faunal succession, unconformity, intrusion, comparative deformation, and comparative metamorphism.

More than half of the book is devoted to setting forth detailed features of sedimentary rocks. Original structures of all kinds are illustrated and discussed. Individuals engaged in sedimentary studies will find these sections especially welcome, not only because the features are adequately illustrated and explained, but because an extensive indexed bibliography accompanies the volume, thus simplifying the problem of assembling additional information about a feature.

Additional chapters on detailed original structures in igneous and metamorphic rocks, though not as extensive as those that deal with sediments, nevertheless seem adequate for the purpose of the book.

WARREN O. THOMPSON

University of Colorado

Bibliography of animal venoms. R. W. Harmon and C. B. Pollard. Gainesville, Fla.: Univ. Florida Press, 1948. Pp. xxx + 340. \$8.00.

The value of a complete bibliography concerning a particular subject, properly indexed, is undoubtedly. The time saved a worker in having an immediate source of information concerning the literature on his subject is usually sufficient to make the time necessary to compile the information well spent. This, unfortunately, is not entirely the case in the present bibliography. The authors have done a tremendous amount of work in its preparation and are to be congratulated upon a fine piece of work, albeit incomplete.

The authors have listed 4,157 titles dealing with animal venoms published since 1875 (rather than 1863, as stated in the foreword). These titles are arranged chronologically by year of publication of the original references, and alphabetically by author under each year. Citations are given to abstracts of the paper as well as to the original publication. Titles in foreign languages have been translated, and all titles are given in English. Ten abstracting journals have been used extensively, and the list of abbreviated journal names is indeed impressive. There is an index of authors whose works are mentioned.

In view of the exhaustive and painstaking work involved in preparing what has been done, it comes as a surprise to find that there is no cross indexing whatsoever,

except for the index of authors. The fact that there is no subject index greatly decreases the value of the book. It is hoped that this is only volume 1 and that the next will include a complete cross reference of the material. As it stands, one must start on page 1 and read every title to find those related to a special interest. Even so the book will save some time for the researcher.

It is also surprising to find the *Zoological Record* missing from the list of references consulted. A quick check of its cross reference of venoms in the Amphibia and Reptilia section shows that only about 50% of the titles listed there are also in this book; e.g. in 1939, of 27 titles in the *Zoological Record*, only 14 were also listed in this book. The same is true of 1944 and 1945. In 1946 only 3 of the 18 titles related to venoms in the *Zoological Record* appear in this volume. The last may be due to publication delays, of course. Possibly too much dependence has been placed upon abstracting

journals rather than on direct checks of the journals concerned. This is shown by the presence of some and absence of other articles which have appeared in *Copeia*. For example, neither Cowles' article on venom in *Hypsiglena* (*Copeia*, 1941, 1, 4) nor Allen and Maier's note on extracting and processing of snake venom (*Copeia*, 1941, 4, 248) is listed, although the senior author of the second paper gave assistance to the authors in the book's preparation! These omissions, though unfortunate, are a normal occurrence in this kind of book and would be cheerfully disregarded if a subject index were available. The lack of the latter, however, makes this volume of doubtful value in a zoologist's library. The book will be useful primarily to those who only wish to know the field of venom well enough to be acquainted with the work done by various authors and the time when such work was done.

JAMES A. PETERS

University of Michigan

Scientific Book Register

- ARNOW, L. EARLE, and REITZ, HENRY C. *Introduction to organic and biological chemistry*. (2nd ed.) St. Louis: C. V. Mosby, 1949. Pp. 795. (Illustrated.) \$5.75.
- CALVIN, MELVIN, HEIDELBERGER, CHARLES, REID, JAMES C., TOLBERT, BERT M., and YANKWICH, PETER F. *Isotopic carbon: techniques in its measurement and chemical manipulation*. New York: John Wiley; London: Chapman & Hall, 1949. Pp. xiii + 376. (Illustrated.) \$5.50.
- CURTIS, BRIAN. *The life story of the fish: his morals and manners*. New York: Harcourt, Brace, 1949. Pp. xii + 284. (Illustrated.) \$3.75.
- HOFBAUER, LUDWIG. *Atemregelung als Heilmittel*. Vienna, Austria: Wilhelm Maudrich, 1948. Pp. 99. (Illustrated.) \$2.50.
- MCDougall, W. B. *Plant ecology*. (4th ed.) Philadelphia: Lea & Febiger, 1949. Pp. 234. (Illustrated.) \$4.00.
- MILNE, E. A. *Vectorial mechanics*. New York: Interscience, 1948. Pp. xiii + 382. (Illustrated.) \$7.50.
- OEHSER, PAUL H. *Sons of science: the story of the Smithsonian Institution and its leaders*. New York: Henry Schuman, 1949. Pp. xvii + 220. (Illustrated.) \$4.00.
- POST, HOWARD W. *Silicones and other organic silicon compounds*. New York: Reinhold, 1949. Pp. 230. (Illustrated.) \$5.00.
- RIDER, JOHN F. *Installation and servicing of low power public address systems*. New York: John F. Rider, 1948. Pp. iii + 204. (Illustrated.) \$1.89.
- RILEY, GARDNER M. *Essentials of gynecologic endocrinology: with sections on the male*. Ann Arbor, Mich.: Caduceus, 1948. Pp. x + 205. (Illustrated.) \$3.00.
- RONCHESE, FRANCESCO. *Occupational marks and other physical signs: a guide to personal identification*. New York: Grune & Stratton, 1948. Pp. xvi + 181. (Illustrated.) \$5.50.
- ROSENFIELD, L. *Nuclear forces*. (Sect. II.) Amsterdam: North-Holland Publ.; New York: Interscience, 1949. Pp. 182-543. (Illustrated.) \$7.50.
- SNYDER, FRANKLIN F. *Obstetric analgesia and anesthesia: their effects upon labor and the child*. Philadelphia-London: W. B. Saunders, 1949. Pp. viii + 401. (Illustrated.) \$6.50.
- STIMSON, DOROTHY. *Scientists and amateurs: a history of the Royal Society*. New York: Henry Schuman, 1948. Pp. xiii + 270. (Illustrated.) \$4.00.
- SYMONDS, PERCIVAL M. *Dynamic psychology*. New York: Appleton-Century-Crofts, 1949. Pp. vii + 413. \$3.75.
- WALTON, HAROLD FREDERIC. *Inorganic preparations: laboratory manual*. New York: Prentice-Hall, 1948. Pp. viii + 183. (Illustrated.) \$3.00.
- WARE, LAWRENCE A. *Elements of electromagnetic waves*. New York-London: Pitman, 1949. Pp. x + 203. (Illustrated.) \$3.50.
- WEISSBERGER, ARNOLD. (Ed.) *Catalytic, photochemical and electrolytic reactions*. (Technique of Organic Chemistry, Vol. II.) New York: Interscience, 1948. Pp. ix + 219. (Illustrated.) \$5.00.
- WERFF, J. TH. VAN DER. *Biological reactions caused by electric currents and by X-rays*. New York: Elsevier, 1948. Pp. xii + 203. (Illustrated.) \$5.00.
- . *Annual report of the Smithsonian Institution*, 1947. (Publ. 3921.) Washington, D. C.: U. S. Govt. Printing Office, 1948. Pp. ix + 471. (Illustrated.) \$2.00.

NEWS and Notes

Robert Gordon Douglas has been appointed professor of obstetrics and gynecology at Cornell University Medical College and obstetrician and gynecologist-in-chief to the New York Hospital. He has been serving as acting director of the joint position since the death of **Henricus J. Stander** last year.

M. L. Crossley, of the American Cyanamid Company, has been made an honorary member of the American Institute of Chemists.

Wilfred F. L. Place has recently been appointed general manager of Abrasifs Durex, Gennevilliers, France.

Franz L. Alt has been appointed assistant and acting chief of the Computation Laboratory of the National Bureau of Standards. Before joining the staff, Dr. Alt was deputy chief of the Computing Laboratory of the Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland.

Harry Nelson, of Bryn Mawr College, has been appointed professor and chairman of the Department of Psychology at Brooklyn College, effective next September. **Edward Girden** is now serving as acting chairman.

Howard E. Brewer, formerly associate botanist at Alabama Polytechnic Institute, recently became assistant professor in the Department of Botany, State College of Washington, Pullman.

H. A. Krebs, professor of biochemistry, University of Sheffield, England, will deliver the sixth Harvey Lecture of the current series at the New York Academy of Medicine on March 17. Dr. Krebs will speak on "The Tri-carboxylic Acid Cycle."

Ernst Mayr, of the American Museum of Natural History, New York, has been elected a corresponding member of the Zoological Society of London.

Clement J. Rodden, chief of the Cer Society, which is concerned with Uranium and Related Materials Section of the National Bureau of Standards, has been named director of the New Brunswick Laboratory of the U. S. Atomic Energy Commission, effective April 3. Other staff appointments are: as assistant to the director, **John E. Donovan**, National Bureau of Standards; as chief of the General Analytical Branch, **Joseph J. Tregoning**, National Bureau of Standards; as chief of the Radiochemistry Branch, **James E. Hudgens**, Oak Ridge National Laboratory; and as chief of the Spectrographic Branch, **Harold R. Mullin**, Shell Oil Company research laboratories.

Frank J. Dunn, formerly of Columbia University, has joined the staff of the University of California Los Alamos Scientific Laboratory's Chemistry and Metallurgy Division.

John W. Ferree, former Indiana Health Commissioner, has been appointed director of the Public Health Division of the American Heart Association.

Visitors to U. S.

Ronald Smelt, formerly of the Royal Aircraft Establishment, England, has been appointed chief of the Applied Mechanics Subdivision at the Naval Ordnance Laboratory, White Oak, Maryland. Mr. Smelt's book on rockets and jets is in process of publication in England.

Thomas G. Room, chairman of the Department of Mathematics, University of Sydney, is serving as visiting professor of mathematics at the University of Tennessee during the current winter quarter.

Fred Jonker, University of Delft, Holland, has joined the University of Delaware's Department of Chemical Engineering as assistant research professor. Dr. Jonker, a specialist in the problems of jet engines, will work with Kurt Wohl in combustion research related to jet propulsion.

Hans Laser, of the Molteno Institute, Cambridge, recently arrived in New York to work on a special problem sponsored by the American Can-

Laser is a guest of the Research Laboratory of St. Vincent's Hospital. While here he will visit a number of universities and institutes in connection with his recent work on the chemotherapy of malaria, in behalf of the Medical Research Council of Great Britain.

Four European medical scientists are attending a one-month course on the use of radioisotopes at the Oak Ridge Institute of Nuclear Studies. They are: **Jean Govaerts**, University of Liège; **Robert Delcourt**, University of Brussels; **H. J. Jongepier**, University of Amsterdam; and **Alexander Robert Taylor Lundie**, of the Royal Army Medical Corps, England.

Enrico Volterra, of Rome, Italy, has been appointed associate professor of mechanics at Illinois Institute of Technology. Dr. Volterra taught mechanics and structures at Rome University and did research on structural problems and materials testing at Cambridge University.

Grants and Awards

Henry C. Sherman, Mitchell professor emeritus of chemistry at Columbia University, has been awarded one of the 1948 Charles Frederick Chandler medals.

Gilbert E. Doan, head of the department of metallurgy and metallurgical engineering at Lehigh University, has received the Stoughton Award for outstanding contributions to the advancement and use of welding. Dr. Doan helped to develop the use of gamma-rays for inspection of welds and castings.

Dontcho Kostoff, director of the Institute for Applied Biology and Organic Development, Academy of Sciences, Sofia, Bulgaria, has been awarded the Medal for Service in Agriculture and Forestry, presented for the first time this year by the Institute for International Relations in Agriculture and Forestry of Prague.

James Zetek was recently awarded the Vasco Nuñez de Balboa decoration by the Republic of Panama in recognition of his work on entomo-

logical problems of Panama and the Canal Zone. Mr. Zetek is presently in charge of the Ancon (Canal Zone) laboratory of the Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture.

Morris E. Leeds, chairman of the board of Leeds and Northrup Company of Philadelphia, recently received the 1948 Edison Medal of the American Institute of Electrical Engineers. Mr. Leeds was cited for his work with electrical precision measuring devices and controls.

Eugene G. Rochow, of Harvard University, has been chosen to receive the third Leo Hendrik Baekeland Award of the American Chemical Society's North Jersey Section. Dr. Rochow was cited for his research on compounds of silicon. The award, established by the Bakelite Corporation, consists of a gold medal and \$1,000, presented biennially to an American chemist.

The National Geographic Society has awarded the Burr prize of \$1,000 to **Arthur A. Allen**, professor of ornithology at Cornell University, for his leadership of an expedition which located the nesting place of the bristle-thighed curlew in western Alaska.

Anna Goldfeder has received an award from the Radiological Society of North America in recognition of her work in radiobiology, particularly for "Anomalous Radiosensitivities of Analogous Mouse Mammary Adenocarcinomas." Dr. Goldfeder is in charge of Cancer Research, Department of Hospitals, New York City, and Department of Biology, New York University.

The Gold Medal of the American Academy of Orthopedic Surgery has been awarded to three University of Texas staff members—**G. W. N. Eggers**, professor of orthopedic surgery, **Thomas Shindler**, resident in orthopedic surgery, and **Charles M. Pomerat**, director of the Tissue Culture Laboratory.

Colleges and Universities

The University of Delaware has appointed Earl Parker Hanson chairman of its Department of Geography.

The Department's research will be integrated with the work of the University's Institute of Inter-American Studies and Research and will be aided by other departments, such as engineering, economics, and agriculture. A contract has been signed with the Office of Naval Research for a report on problems of adaptation to the humid tropics.

The Yale University Graduate School and School of Medicine are initiating a new program for the study of microbiology. The new department, which includes faculty members from four Graduate School Departments and the Medical School's Section of Preventive Medicine, will bring together courses previously offered by the Departments of Bacteriology and Immunology, Plant Science, Physiological Chemistry, and Zoology.

Harvard University's Mallinckrodt Chemical Laboratory has placed on display 45 pieces of scientific apparatus used at Harvard during the Colonial period. The equipment includes electricity-making machines designed by Benjamin Franklin, chemical devices invented by Joseph Priestley, a "camera obscura" (forerunner of the modern camera), and other instruments used in astronomy, optics, mechanics, electrostatics, hydrostatics, pneumatics, biology, magnetism, chemistry, and mineralogy. The collection was assembled under the direction of David Wheatland of the Physics Department.

Columbia University's Industrial Engineering Department, in cooperation with the Department of Sociology, is conducting a 4-month seminar in "The Theory of Organization and Management." The human element in production will be studied by engineers, social scientists, and industrial executives. Sessions are held Tuesday from 2-4 p.m. in Room 308, Mines Building, Columbia University, Broadway and 117th Street, New York City.

The Massachusetts Institute of Technology will hold an international convocation on the social implications of scientific progress, March 31-April 1. The subjects will be "The Twentieth Century, Its Promise and Its Realization," and "What the Nation Expects of Science and Technology." Speakers will include Karl T. Compton,

ton, chairman of the Research and Development Board of the National Military Establishment; Sir Henry Tizard, chairman of the British Ministry of Defense's Research Policy Committee; Fairfield Osborn, president of the New York Zoological Society; Percy W. Bridgman, Hollis professor of mathematics and natural sciences, Harvard University; Jacques Maritain, professor of philosophy, Princeton University; and Sir Richard Livingstone, of Oxford University.

Summer Programs

Yale University's annual Summer School of Alcohol Studies will be held in two sessions this year: at Trinity University, San Antonio, Texas, from June 6 to June 29; and at Yale from July 8 to August 5. E. M. Jelinek, director of the school, will be assisted by lecturers from other universities and representatives from other institutions of education, research, treatment, and rehabilitation. Applications for admission to the western session will be received up to April 1; for the eastern session to April 15. A prospectus and application blank for either session may be obtained from the Executive Secretary, Summer School of Alcohol Studies, Yale University, New Haven, Connecticut.

Duke University will hold its 9th annual session of the Institute for Mathematics Teachers, August 8-12, at Durham, North Carolina. The general theme of the Institute will be "Mathematics at Work" which will be presented in 10 study groups. Programs with detailed information will be available April 1 from W. W. Rankin, Professor of Mathematics, Duke University, Durham, North Carolina.

University of Michigan's College of Engineering is sponsoring a symposium on engineering structures this summer. S. P. Timoshenko, Stanford University, will give a course in "Theory of Plates and Shells," and R. V. Southwell, Imperial College of Science and Technology, London, will present "Relaxation Methods with Application to Aircraft Structures." Advanced courses in plasticity, dynamics, theory of structures, elasticity, and other related subjects will also be

ffered as well as an extensive program in applied mathematics. Further information may be obtained from S. L. Eriksen, Engineering Mechanics, University of Michigan, Ann Arbor.

The University of Virginia will conduct summer courses in botany, zoology, and biology at Mountain Lake Biological Station from June 16-August 24. Application blanks and further information may be obtained from the Registrar, Summer Session, University Station, Charlottesville, Virginia.

Industrial Laboratories

Television in natural color for the teaching of surgery and medicine will be demonstrated at the annual meeting of the American Medical Association at Atlantic City in June. This program, sponsored by Smith, Kline and French Laboratories of Philadelphia and the University of Pennsylvania, will enable large groups of medical students to study surgical techniques and medical procedures in full color detail.

The Laboratory of Microchemistry, formerly at 366 Fifth Avenue, New York City, is now located just outside the city at 705 George Street, Teaneck, New Jersey. The Laboratory is under the direction of Carl Niedeke, its founder.

Meetings and Elections

The "Atlantic Ocean Basin" is the subject of a lecture series being presented at a number of colleges and universities by Maurice W. Ewing, professor of geology, Columbia University, and research associate, Woods Hole Oceanographic Institution, under sponsorship of the Sigma Xi National Lectureships. The three remaining lectures of the series will be given February 28 at the University of Cincinnati, Ohio; March 1—Ohio University, Athens; and March 4—University of Tennessee, Knoxville.

Wellesley College will hold a 3-day Science Conference March 16-18. The theme of the all-college conference energy, and James Bryant Conant, president of Harvard University, will deliver the keynote address, "Science and Common Sense." Among the Committee before April 1. Members

other speakers will be Gerty Cori, Nobel prize winner; Cecilia Payne-Gaposchkin, of Harvard Observatory; Robert F. Bacher, of the U. S. Atomic Energy Commission; Wolfgang Köhler, leader of the Gestalt system of psychology; and Edmund W. Sinnott, director of the Sheffield Scientific School of Yale University. Delegates from 70 colleges are expected to attend.

A 2-day symposium on "Organic Sulfur Compounds as Related to Petroleum" will be held in connection with the national meeting of the American Chemical Society in San Francisco, March 28-April 1. The best methods of combating the costly effects of sour crude oil, which derives its undesirable properties from its high sulfur content, will be presented in 29 technical papers by oil chemists of Great Britain and the U. S. Arlie A. O'Kelley, vice chairman of the Division of Petroleum Chemistry, will preside.

The newly formed Inter-Society Corrosion Committee of the National Association of Corrosion Engineers will hold its 1949 conference during the week of April 11, in Cincinnati, Ohio, coincident with the NACE 1949 conference.

The International and Fourth American Congress on Obstetrics and Gynecology will meet at the Hotel Statler (formerly Hotel Pennsylvania), New York City, May 14-19. Topics under discussion will be physiology of human reproduction, the pathology of human reproduction, social and economic problems, neoplastic diseases of the reproductive system, and obstetric and gynecologic procedures. All inquiries regarding the meeting should be addressed to Fred L. Adair, 24 West Ohio Street, Chicago 10, Illinois.

The American Society of Electroencephalography will hold its annual meeting in Atlantic City at the Chalfonte-Haddon Hall Hotel, June 11-12. Those wishing to submit papers should send two copies of title and abstract to Secretary Robert S. Schwab, Massachusetts General Hospital, Boston 14, and one copy to the proper representative on the Program Committee before April 1. Members

are invited to submit demonstrations and exhibits, a description of which should also be submitted before April 1. Accepted papers will be announced by April 15.

The annual conference of Health Officers and Public Health Nurses of New York State will be held June 20-23 at Lake Placid. The Association of School Physicians will hold its annual meeting on the opening day.

The Heat Transfer and Fluid Mechanics Institute will hold its annual meeting June 22-24 on the University of California's Berkeley campus. The conference will be presented by California engineering colleges and engineering and scientific societies. A number of technical papers dealing with phases of the fundamental nature of heat transfer and fluid flow will be presented. For further information, write: Department of Institutes, University of California Extension, Berkeley.

The Special Committee on Fungi for the International Botanical Congress at Stockholm has made the following new appointments; Johanna Westerdijk, Netherlands; D. P. Rogers, C. W. Emmons, and G. W. Martin, U. S.; Rolf Singer, Argentina; S. P. Wiltshire, England; M. Le Gal, France; M. A. Donk, Dutch East Indies; and B. B. Mundkur, India. Previous appointees are C. L. Shear, K. B. Boedijn, R. Ciferri, R. Maire, J. A. Nannfeldt, F. Petrak, F. J. Seaver, E. M. Wakefield, A. M. Bottomley, W. J. Lütjeharms, J. Ramsbottom, A. Trotter, and W. H. Weston. T. A. Sprague and J. Lanjouw are *ex officio* members of all committees. The Fungi Committee will consider proposals to modify the present International Rules of Botanical Nomenclature with respect to fungi. The new appointments were made at the International Conference on Botanical Nomenclature held at Utrecht, Holland, in June 1948.

The Royal Astronomical Society of Canada elected the following officers at its annual meeting this month: president, Andrew Thomson, Controller of the Meteorological Service of Canada; vice presidents, C. S. Beals, Dominion Astronomer, Ottawa,

and J. F. Heard, David Dunlap Observatory, Richmond Hill, Ontario; general secretary, E. J. A. Kennedy, Toronto; general treasurer, J. H. Horning, Toronto; recorder, H. W. Barker, Toronto; librarian, D. W. Best, Toronto.

The Southern Section of the American Society of Plant Physiologists and the Association of Southern Agricultural Workers have elected officers for the coming year—chairman: E. M. Emmert, University of Kentucky; vice chairman: Henry C. Harris, Florida Agricultural Experiment Station, Gainesville; secretary-treasurer: G. M. Shear, Virginia Agricultural Experiment Station, Blacksburg; directors: L. L. Danielson, Virginia Truck Experiment Station, Norfolk; H. B. Sprague, Texas Agricultural Research Foundation, Renner; I. E. Miles, Mississippi State College.

The Southeastern Allergy Association elected the following officers at its recent meeting: president, Oscar Swineford, professor of medicine, University of Virginia; vice president, Oscar Hansen-Pruss, chief of Duke University's Allergy Clinic; executive committee, George F. Hieber, St. Petersburg, Florida, and Louis D. Hoppe, Jr., Atlanta, Georgia.

Deaths

William Alton Taylor, 85, retired chief of the Bureau of Plant Industry, U. S. Department of Agriculture, died February 9.

William M. White, 77, former manager and chief engineer of the hydraulics department, Allis-Chalmers Company, died at his Coral Gables, Florida home February 9.

Henry Francis Atherton, 65, former president of the Allied Chemical and Dye Corporation and member of the Chemical Advisory Committee of the Army-Navy Munitions Board, died February 10.

Louis A. Olney, 74, president of the Howe Publishing Company of New York, who had been head of the Chemistry Department, Lowell Textile Institute, for 30 years, died February

11 in Jacksonville, North Carolina. Dr. Olney and his wife, enroute to Florida at the time, both died from injuries resulting from an auto accident.

The U. S. National Commission for Unesco announces the publication of "Study Abroad," a handbook of fellowships, scholarships, and educational exchange listing over 10,500 opportunities for international study in 166 subject fields in 27 countries, including the U. S. The largest number of awards is in science, particularly medicine, public health, engineering, and chemistry. The handbook was prepared by William D. Carter, head of the Office for the Exchange of Persons, Unesco House, Paris. The aim of the publication is to increase the number and quality of candidates applying for fellowships, to suggest to prospective donors how new prospects can be developed, and to indicate possible overlapping as well as areas of outstanding need. Copies, published in English and in French, will be available at \$1 from the Columbia University Press, New York 27, N. Y.

The National Registry of Rare Chemicals, 35 West 33rd Street, Chicago 16, Illinois, has submitted the following list of wanted chemicals: tribromogermane, trichlorogermane, trigermane, vacenine acid, trimethylene sorbitol, glucooctose, glucononose, o-aminoatropic acid, spinulosin, 4-hydroxyacridine, 4,5-dihydroxyacridine, stannous fluoride, homomyristicyl amine, homopiperonyl amine, carbonyl sulfide, 3-tropanone, urobilinogen, thymidine, phenolphthalein mono- β -glucuronide, titanium dichloride, cyclooctatetraene, kaempferol, 4-methoxy catechol.

Indian meteorologists will survey the western Himalayan ranges, including the 17,000-foot Bara Lacha Pass, next April to find a site for the high-altitude meteorological research station recently authorized by the Central Government. The sum of \$900,000 has been appropriated for this project. According to S. K. Banerji, director-general of observatories of India, plans for improving the scope of existing observatories provide for equipping the general charge of the projects.

Kodaikanal Astronomical Observatory (South India) with a modern ionosphere for studying changes on the surface of the sun. Two sensitive seismographs recently acquired from the U. S. have been installed at the Poona and Madras Observatories. Negotiations are now in progress to enlarge further the present facilities for meteorological research by establishing a field magnetic observatory 35 miles southeast of Bombay.

Past environments of reef-building organisms will be studied in a research program by Columbia University graduate students under the direction of Norman D. Newell, professor of geology at Columbia, and curator of Historical Geology and Fossil Invertebrates at the American Museum of Natural History. The project, one of the most extensive undertaken in the field of paleo-ecology, is designed to provide the first comprehensive conception of conditions under which reef-building organisms existed and the manner in which associated limestones were formed. Several years of field and laboratory study of both ancient reefs and their modern counterparts will be necessary to bring the project to completion. The reefs to be studied are those in the West Texas-Southeast New Mexico oil-producing regions and include the famous limestones in which the Carlsbad Caverns are located. These extensive deposits were constructed mainly through the agency of huge colonies of plant and animal life which existed in the seas of the Permian period. The research is being supported by the Humble Oil and Refining Company.

The Museum of Northern Arizona at Flagstaff has plans for three archaeological projects in Arizona this spring and summer, all financed by a grant from the Viking Fund. One group, under the direction of John C. McGregor, of the University of Illinois, will excavate pithouse sites near Red Butte. Another, headed by Dick Shutler, of the University of California, will explore sites of a preceramic horizon near Sedona. Fred Wendorf, Jr., of Harvard, will conduct a third party in excavating sites dating about 500 A. D. near Holbrook. Harold S. Colton, the Museum director, is in